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Environmental Assessment: Source Test and Evaluation Report - Lurgi (Kosovo) Medium-BTU Gasification

Radian Corp.
Austin, TX

Prepared for

Industrial Environmental Research Lab.
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K. W. Lee, et al

Radian Corporation
Austin, Texas

August 1981

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Environmental Assessment: Source Test and Evaluation Report - Lurgi (Kosovo) Medium-BTU Gasification, Final Report

by

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Research Triangle Park, NC 27711

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16. ABSTRACT
The report summarizes an environmental data acquisition program involving a commercial-scale, medium-Btu, Lurgi gasification plant in the Kosovo region of Yugoslavia. The program is sponsored jointly by the U.S. EPA and the government of Yugoslavia. The objective of the program was to characterize potential environmental problems associated with coal gasification in a Lurgi plant. Since Lurgi plants are being planned for U.S. gasifiers, the program enabled the EPA to study firsthand the possible environmental problems which might be encountered. The Source Analysis Model/IA (SAM/IA) was applied to the best values of flow rates and concentrations of chemical species from all field tests to identify and prioritize potentially harmful discharges. The model was also applied to specific chemical species plantwide in the gaseous discharge streams. The primary conclusion of this environmental assessment model is that the process exhibits a significant potential for pollution. All discharge streams are potential vehicles for pollutant transfer from the process to the environment. The streams with the highest priority for control, based on their potential for adverse health effects in the three discharge media, are the H2S-rich waste gas, phenolic wastewater, and heavy tar (solid). When evaluated using SAM/IA, sulfur compounds posed the largest health problem from gases.

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ABSTRACT

This report summarizes the results to date of the environmental data acquisition program which is jointly sponsored by the U.S. Environmental Protection Agency and the Government of Yugoslavia. The subject of this test is a commercial-scale, medium-Btu, Lurgi-type gasification facility which is currently operating in the Kosovo region of Yugoslavia.

The objective of this test program is to characterize potential environmental problems associated with the gasification of coal in a Lurgi-type gasification plant. Since Lurgi plants are being planned for U.S. gasification facilities, this study provides EPA with an opportunity to test firsthand, the possible environmental problems which might be encountered.

The Source Analysis Model/1A (SAM/1A) was applied to the best values of flow rates and concentrations of chemical species from all field tests to identify and prioritize potentially harmful discharges. This model was also applied to specific chemical species plantwide in the gaseous discharge streams.

The primary conclusion of this environmental assessment model is that the process exhibits a significant potential for pollution. All discharge streams are potential vehicles for pollutant transfer from the process to the environment. The streams with the highest priority for control based on their potential for adverse health effects in the three discharge media are the H_2S-rich waste gas, phenolic wastewater and heavy tar (solid). When evaluated using the SAM/1A, sulfur compounds pose the largest potential for adverse health effects plantwide from the gaseous discharges.

The ash from the Kosovo facility has a very low potential for adverse environmental effects, as evidenced by the results of bioassay of the ash and leachates from the ash. Trace elements were found to be much less significant than trace organics in their contribution to the discharge severity of the waste streams. Levels of trace elements found by the Resources Conservation Recovery Act method of extraction were greater than an order of magnitude below levels specified in the Extract Procedure Toxicity Test.

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SECTION 1

INTRODUCTION

An international program, sponsored by the Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) is being conducted in the Kosovo region of Yugoslavia. The program was designed in response to a need for representative data on environmental problems associated with the commercial application of Lurgi coal gasification technology. The program, conducted over a three-year period, is a joint effort among scientists from the U.S. and Yugoslavia. The participating organizations, and their roles, are shown below.

Organization	Location	Function
EPA/IERL	Research Triangle Park, North Carolina	Funding Agency
Radian Corporation	Austin, Texas	Prime Contractor, Coordinator
Rudarski Institute	Belgrade, Yugoslavia	Sampling/Analyses/Data Analyses/Overseas Coordination
Kobinat Kosovo	Obilic, Yugoslavia	Plant Operation/Sampling
Kosovo Institute	Obilic, Yugoslavia	Sampling/Trace Element Analyses
Institute za Primenu	Belgrade, Yugoslavia	On-Site GC Analyses/Organic Analyses

The opportunity to make a comprehensive environmental characterization of an operational, commercial-scale, Lurgi-type coal gasification plant was considered valuable since a number of U.S. companies have announced plans to construct such plants. Thus, characterization of selected process and discharge streams from the Kosovo plant provides a valid insight into problems that must be considered by U.S. designers in developing process modification and/or control schemes necessary to meet U.S. environmental requirements.

The test program was conducted in four phases, as follows:

Phase	Objective
I	Identify and measure major and minor pollutants in discharge streams.
II	Identify and measure trace pollutants in discharge streams.

III Characterize ambient air pollutants in the vicinity of the plant.

IV Measure fugitive emission rates from leak sources in the plant.

This report presents information on major, minor, and trace pollutants in the discharges from the Kosovo plant. The results from testing in Phases I and II are combined here to provide a "best value" for use in evaluating the discharges. This report includes not only an assessment of specific discharges but also an evaluation of discharge severity as determined by EPA/IERL's Source Analysis Model/1A (SAM/1A) model for prioritizing pollutants on the basis of their potential for causing adverse health and ecological effects.

1.2 PLANT DESCRIPTION

The Kosovo Gasification Plant is part of a large mine-mouth industrial complex located near the city of Pristina, in the Kosovo Region of Southern Yugoslavia. The complex consists of a coal mine, a coal preparation plant, the gasification plant, a steam and power generation plant, an ammonia plant, and an air separation plant.

The gasification plant consumes dried coal (lignite) and produces two primary products: a medium-Btu fuel gas and hydrogen for use in ammonia synthesis. Several by-products are also produced: tar, medium oil, naphtha, and crude phenol.

Run-of-mine coal from the Kosovo mine is dried by the Fleissner process and sized to select particles ranging in diameter from 6 mm to 60 mm. The coal is then fed to the Lurgi-type gasifiers where it is reacted with oxygen and steam at 2.5 MPa (25 atm) pressure. The crude product gas is cooled, cleaned, and transported by pipeline to the utilization site.

As the crude product gas is quenched and cooled, tars, oils and naphtha are condensed and removed in a penolic water stream. Acid gases (H_2S and CO_2) are removed by the product gas by sorption with cold methanol (Rectisol process).

The acid-gas-rich methanol is regenerated, releasing a waste gas rich in H_2S, which is flared, and a CO_2-rich waste gas which is vented to the atmosphere. Tars and oils are removed from the phenolic water stream by decantation, after which the water soluble organics (crude phenols) are recovered by extraction with diisopropyl ether. Four liquid by-products; tar, medium oil, naphtha, and crude phenol are collected and held in storage tanks for futher use. Ammonia, removed from the phenolic water by steam-stripping, is vented to the atmosphere. A more detailed description of the plant and its operation is presented in Section 2 of this report.

1.3 RATIONALE FOR PHASE II TESTING

The program conducted at Kosovo presented an unusual opportunity to examine the environmental character of an operational, commercial-scale Lurgi-type coal gasification plant. Although the control technologies used at Kosovo would not be considered to be "best available" by current U.S. standards, the control problems facing U.S. Lurgi facility operators will be similar to those found at Kosovo. Therefore, a study of the waste streams at Kosovo should aid U.S. plant designers in developing process modifications and control schemes to meet U.S. environmental requirements.

As stated in Section 1.1, the objective of Phase II testing was to identify and measure trace pollutants in the discharge streams from the plant. The test plan developed for Phase II, therefore, comprised an examination of the total gasification plant, including coal preparation, product-gas cleaning and by-product recovery and storage operations which are integrated with the gas generation operation. Other facilities in the Kosovo industrial complex, (ammonia plant, air separation plant, steam and power generation plant, etc.) were not examined during this program because they were not of primary interest to EPA's synthetic fuel program and/or it was felt that adequate data existed already on such facilities.

1.3.1 Stream Selection

Process and discharge streams in the plant sections examined were selected for study if they met one or more of the following criteria:

- high discharge rate,
- significant pollutant concentration,
- trace pollutant characterization, and
- information value.

Streams exhibiting a high discharge rate were selected for study because at the rates involved (e.g., the CO_2 rich waste gas stream with a design flow rate of 2400 m^3/gasifier-hour), even very low concentrations of moderately toxic pollutants could result in a significant environmental burden.

Streams exhibiting a moderate to low discharge rate were selected for study based on their significant pollutant concentration expressed as discharge severity (a research and development prioritization method). Discharge severity is an expression of the potential for adverse health and ecological effects exhibited by a component in the stream, and is based not only on the toxicity of that component but also on its concentration. Thus it may be seen that highly toxic components at low concentrations and moderately toxic components at high concentrations both would exhibit high discharge severities.

Streams (and sampling points) were selected for study based on a need for information on the fate of trace elements and trace organics throughout the process. In many cases, streams selected for other reasons were studied also for trace element and trace organic character.

The final criterion for stream selection was information value. Process and discharge streams were selected for study if they could be expected to provide information essential to a better understanding of plant and process operations or would be useful in determining the fate of important compounds through the process.

1.3.2 Stream Parameters Selection

Parameters were selected that would provide the data necessary for a physical and/or chemical characterization of the stream under examination. With gaseous streams, for example, velocity, temperature, pressure, actual molecular weight and moisture content (physical parameters) were measured. Analyses were made for fixed gases, aliphatic and aromatic hydrocarbons, sulfur species, and nitrogen species (chemical parameters). These values provided a basis for the calculation of stream flow rates, compositions, mass flow rates, mass balances, and other values useful in gas stream characterization.

Aqueous streams were characterized by determining values for standard water quality parameters (such as BOD and COD), physical properties (pH, temperature), trace pollutants, and dissolved and suspended solids.

Solid and organic liquid streams were characterized by proximate, ultimate, and trace pollutant analyses. In addition, leachate studies were performed on solid wastes.

Bioassay screening tests were performed on selected streams to provide information on their toxic and mutagenic characteristics.

1.4 SAMPLING AND ANALYTICAL METHODOLOGY

Standard EPA-approved sampling methods were used for most of the Phase II testing. In some cases the standard methods were modified in response to specific sample or stream conditions found at the Kosovo plant, or other governing factors such as mechanical configuration of the sampling point or requirements of the plant's operating schedule. Detailed descriptions of sampling methods used during Phase II of the Kosovo program are given in Section 4 of this report, where any deviations from standard practices, and the improvements that resulted, also are discussed.

The methods employed in the analyses of samples collected during Phase II are also described in Section 4. The methods include standardized analytical procedures approved by EPA, ASTM, DIN (German Institute for Standardization), and GOST (Soviet State Committee on Standards).

1.5 RESULTS

The results of Phase II testing corroborate substantially those obtained during Phase I of the Kosovo program. In addition, new information obtained during Phase II about the aqueous and solid discharges from the plant, and about trace organic and inorganic pollutants gives a more complete understanding of the environmental character of this specific gasification plant.

In developing the information contained in this report, all calculations and interpretations are based on the best values for data obtained during both Phase I and Phase II of the test program. The best values were selected based on scientific and engineering judgment, with full consideration for factors that might influence their selection, such as:

- plant operating conditions at the time the samples were taken,
- precision and reliability of specific analytical techniques, and
- measured or design flow rates.

The "Best value" data were then modeled, using EPA's SAM/1A, to provide an estimate of the potential health and ecological effects associated with the plant's discharge streams. Application of SAM/1A to discharge streams gives values by which streams (and stream components) may be ranked according to their discharge severity, or potential for adverse environmental effects. Based on an interpretation of the results from the SAM/1A model, a number of conclusions can be drawn. The conclusions, presented in the following paragraphs, may be used as a basis for the selection of control technology suitable for application to similar gasification plants planned for construction in the U.S.

The primary conclusion is that the uncontrolled process exhibits a significant potential for environmental pollution. All discharge media, air, water, and land are potential receptors for pollutant transfer from one or another of the plant's discharge streams. Most of the major discharge streams sampled were found to contain pollutants at levels which, if uncontrolled, are sufficient to cause concern for human health and the ecology. However, control measures specific to the stream and/or pollutant can be applied and should reduce absolute pollutant release to levels that are acceptable environmentally.

The total weighted discharge severity (TWDS) is a means of estimating the severity of a stream using the SAM/1A. TWDS is the product of the total discharge severity (TDS) for a discharge stream and the stream flow. TDS is the summation of pollutant concentrations devided by their respective discharge multimedia environmental goals (DMEG's) for a given stream and discharge medium. The streams with the highest priority for control (greatest total weighted discharge severity) based on their potential for adverse health effects, in the three discharge media are:

- H_2S-rich waste gas (air),
- phenolic wastewater (water), and
- heavy tar (land).

The greatest potential for adverse environmental effects results from gaseous discharges, not only as a result of their severity, but also due to the number of streams that may be significant sources of pollutants. Fourteen gaseous discharge streams were shown to be major potential sources of pollutants, compared to two each for aqueous and solid streams. Figure 1-1 illustrates the ranking of these streams in each medium, according to their TWDS (= Log_{10} Flow).

It was found that polynuclear aromatic compounds (PNA's) contribute greatly to the discharge severity of discharge streams containing tar: i.e., the heavy tar solid waste stream and the gaseous discharge from the low pressure (LP) coal lock vent (where tar makes up a large portion of the particulate matter discharged in that stream). Benzo(a)pyrene and 7,12-dimethylbenz-(a)anthracene were identified as the most significant PNA's in the Kosovo tar.

Trace elements were found to be less significant than trace organics in their contribution to the discharge severity of the waste streams. However, mercury was found in the phenolic wastewater at a level exceeding the threshold level at which concern for adverse health effects begins. Evaluation of the analytical data for the phenolic water also revealed that, while the Phenosolvan process is effective in removing most of the phenolic material from the aqueous waste stream and reducing the concentrations of several important PNA's to undetectable levels, a significant amount of organic matter, including some phenols, remained in the phenolic water after treatment.

The ash from the Lurgi-type gasification process was found to be of low concern for adverse health or ecological effects. The results of Resource Conservation and Recovery Act extraction procedure (RCRA EP) leaching studies and bioassay on the ash indicated little or no toxicity. The tar streams, however, as mentioned above, are potentially quite hazardous and probably will require controlled disposal (e.g., incineration) in U.S. gasification plants.

In summary, Lurgi-type coal gasification technology, as examined at the Kosovo plant, presents a significant potential for adverse environmental effects. However, application of the proper control technology, which is currently available, should permit the commercial operation of such a plant in the U.S. However, the effectiveness of these controls needs to be determined once commercial plants are operating in the U.S.

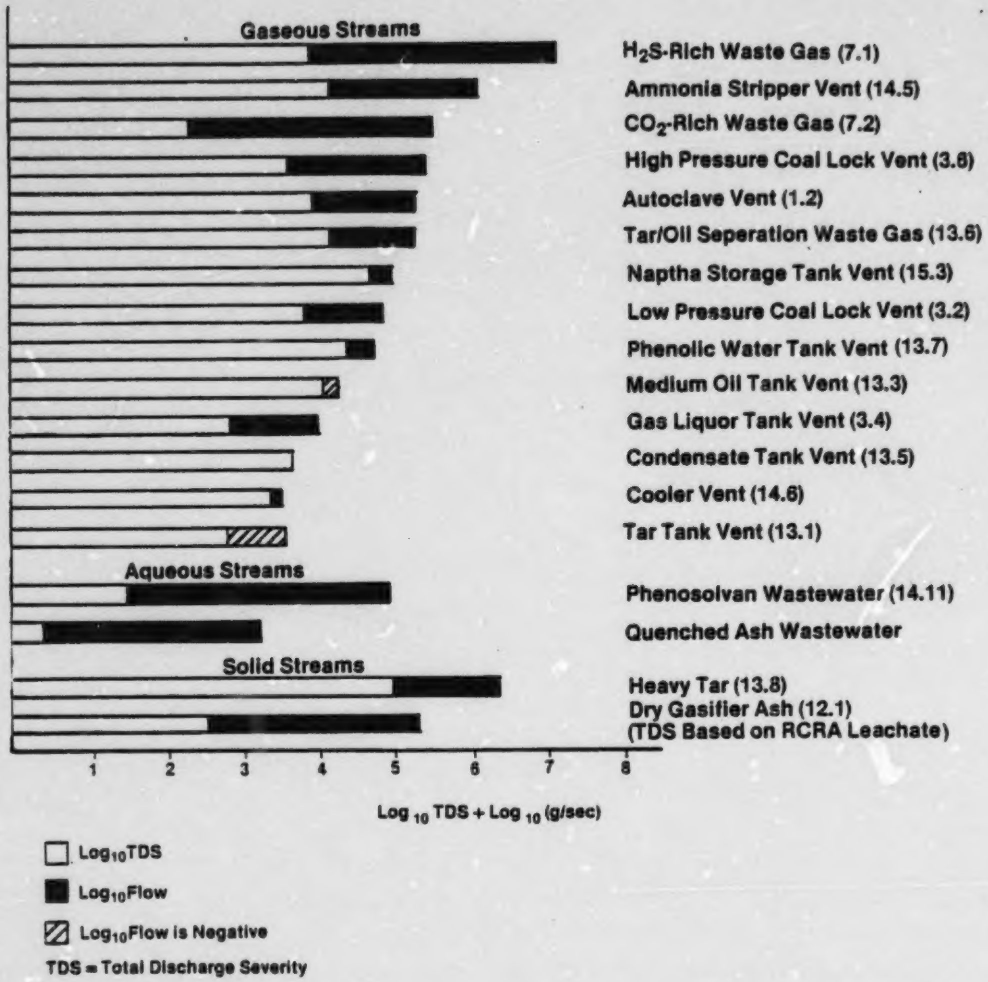


Figure 1-1. A Comparison of the total weighed discharge severity values (health) for key Kosovo gaseous, aqueous, and solid streams.

SECTION 2

PLANT DESCRIPTION

The Kosovo Gasification Plant is an integral part of a large mine-mouth industrial complex. As shown in Figure 2-1, this complex is located near the city of Pristina, in the Kosovo Region of southern Yugoslavia.

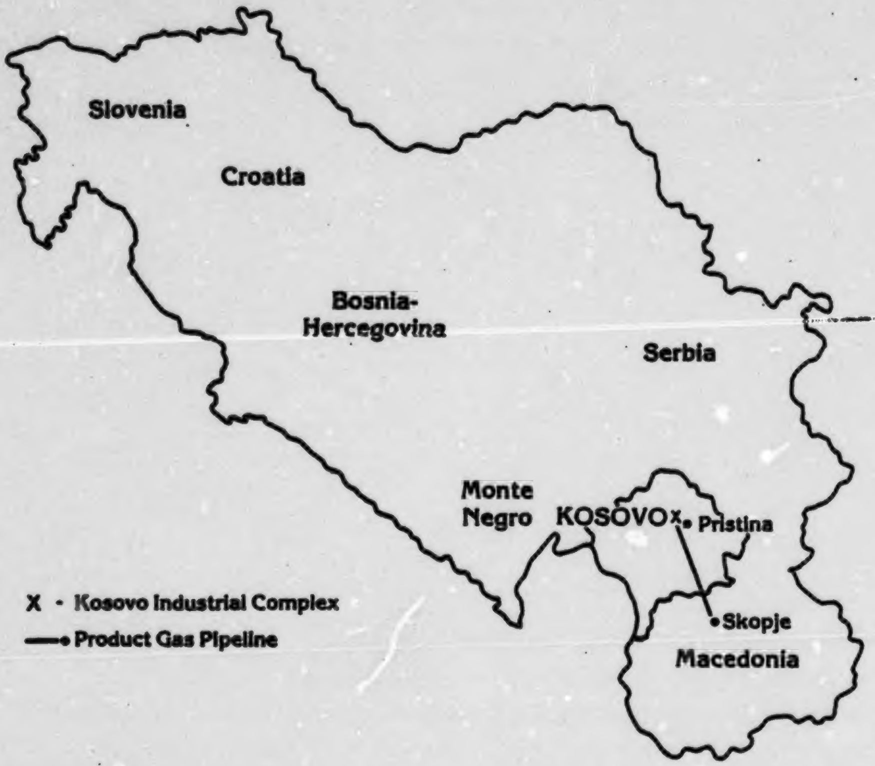
A block diagram of the Kosovo complex is shown in Figure 2-2. The complex consists of a gasification plant, an ammonia plant, an air separation plant, steam and power generation plants, coal preparation facilities, and a coal mine. In the coal preparation section, run-of-mine coal is dried, crushed, and sized. Coal particles between 6 and 60 mm in diameter are routed to the gasification plant. Fines are used as fuel in the steam and power plants while particles larger than 60 mm are recycled. The steam and power plants produce export power as well as the steam and electricity required by the Kosovo complex. The gasification plant produces a medium-Btu fuel gas having a net heating value of approximately 14 MJ/m^3 at 25°C (360 Btu/scf), hydrogen, and liquid by-products. The hydrogen produced in the gasification plant is used as an ammonia synthesis feedstock. The liquid by-products are consumed as fuel in the steam plant. The air separation plant supplies oxygen to the gasification plant and nitrogen to the ammonia plant.

2.1 KOSOVO GASIFICATION PLANT

The Kosovo gasification plant is a commercial-scale facility employing Lurgi-type technology to produce a medium-Btu fuel gas from coal. Figure 2-3 shows the design flow rates of the plant's major inlet and outlet streams. These data indicate that the plant is designed to produce 25 Mg (65,000 m^3 at 25°C) of product gas for every 80 Mg of dried coal consumed.

The Kosovo plant is smaller than proposed first generation U.S Lurgi gasification facilities, but it contains many of the process units which are likely to be employed in future U.S. Lurgi plants. These units include oxygen-blown, Lurgi-type gasifiers, a tar/oil separation facility, a Rectisol acid gas removal unit, a Phenosolvan wastewater treatment unit, and by-product recovery/storage facilities. For this reason, the plant is felt to be representative of many aspects of the Lurgi gasification facilities which are being considered for commercialization in the U.S.

A simplified process flow sheet of the Coal Preparation and Gasification plants is shown in Figure 2-4. Run-of-mine coal is crushed, sized, and dried in the Coal Preparation section. In the Gas Production section, dried coal particles between 6 and 60 mm in diameter are gasified in one of six oxygen-blown, Lurgi-type gasifiers. The hot product gases generated in the gasifiers are cooled and routed to the Rectisol section where acid gases such as CO_2, H_2S, and HCN are removed. Clean product gas is then routed to a cryogenic H_2 separation unit and/or a Distribtuion system through which it leaves the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Bosnia-
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Serbia
Monte
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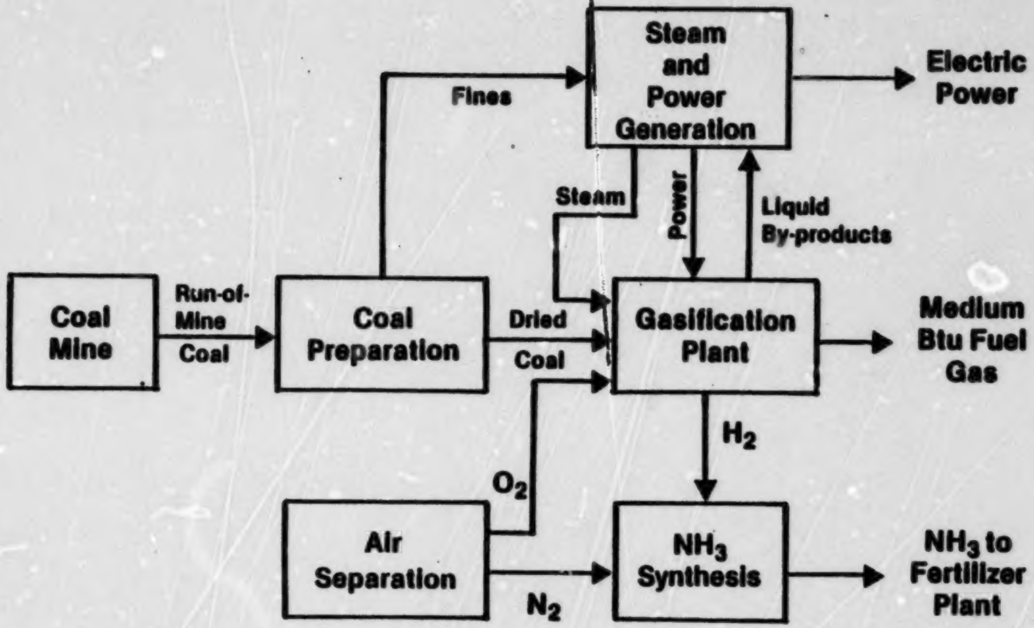
KOSOVO
X
Pristina
Skopje
Macedonia
X - Kosovo Industrial Complex
Product Gas Pipeline

Figure 2-1. Regional map of Yugoslavia showing the location of the Kosovo industrial complex.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Run-of-Mine Coal
Coal Preparation
Dried Coal
Gasification Plant
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O_2
Air Separation
N_2
NH_3 Synthesis
NH_3 to Fertilizer Plant

Figure 2-2. The Kosovo industrial complex.

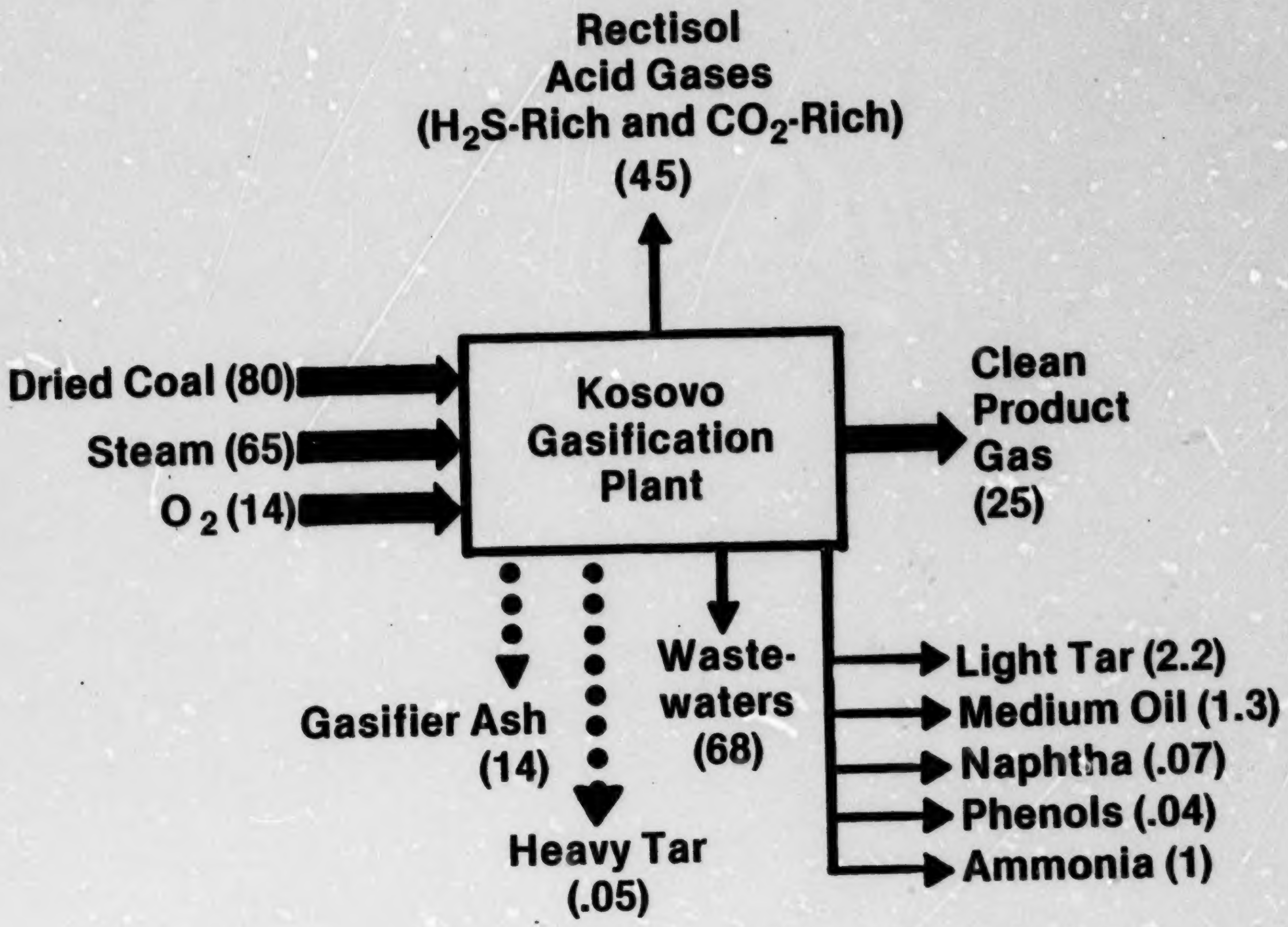

Rectisol
Acid Gases
(H_2S-Rich and CO_2-Rich)
(45)
Dried Coal (80)
Steam (65)
O_2 (14)
Kosovo
Gasification
Plant
Clean
Product
Gas
(25)
Gasifier Ash
(14)
Heavy Tar
(.05)
Waste-
waters
(68)
Light Tar (2.2)
Medium Oil (1.3)
Naphtha (.07)
Phenols (.04)
Ammonia (1)

Figure 2-3. Design flow rates of key streams in the Kosovo gasification plant (all values in megagrams/hr. based on 5 gasifiers in service).

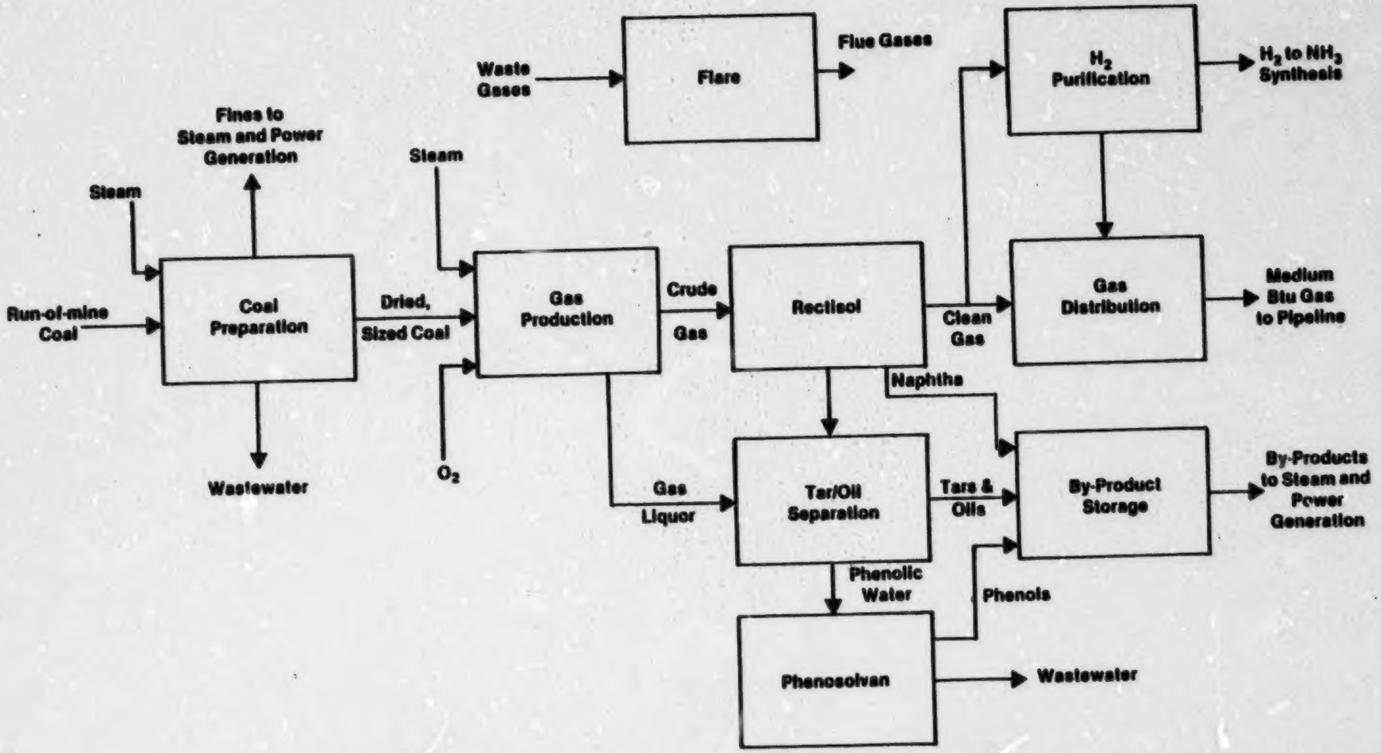

Run-of-mine Coal
Steam
Coal Preparation
Fines to Steam and Power Generation
Wastewater
Dried, Sized Coal
Steam
O_2
Gas Production
Crude Gas
Gas Liquor
Waste Gases
Flare
Flue Gases
Rectisol
Clean Gas
Naphtha
Tar/Oil Separation
Tars & Oils
Phenolic Water
Phenosolvan
Phenols
Wastewater
H_2 Purification
H_2 to NH_3 Synthesis
Gas Distribution
Medium Btu Gas to Pipeline
By-Product Storage
By-Products to Steam and Power Generation

Figure 2-4. Simplified flow diagram of the Kosovo coal preparation/gasification plant operations.

gasification plant. Ash generated in the gasifiers is water-quenched and disposed of in a landfill. Condensed gas liquors generated as a result of product gas cooling are sent to the Tar/Oil Separation section.

In the Tar/Oil Separation section, organic liquid by-products such as light tar and medium oil are separated from the plant's condensed gas liquor streams. These by-products are sent to the By-Product Storage section. A sludge consisting of heavy tar and dust is also generated in the tar separation process. This sludge is disposed of in a landfill.

The wastewater leaving the Tar/Oil Separation section is routed to the Phenosolvan section where volatile inorganics, such as CO_2 and ammonia, are steam-stripped from the wastewater. Crude phenols are then extracted from the wastewater using diisopropyl ether and sent to the By-Product Storage section. The extracted wastewater is supposed to be treated in a biological treatment unit before being discharged. However, this unit was not in service during the Phase II test program.

While the process flow scheme at Kosovo is representative of proposed U.S. Lurgi plant designs, the environmental control practices followed at the Kosovo plant are not. Many of the plant's waste streams are 'controlled' but none of the controls employed would be characterized as 'best available' by current U.S. standards. Thus, while the discharges that enter the environment at Kosovo are not representative of those that would be encountered in similar U.S. facilities, the type of control problems facing U.S. Lurgi plant operators will be similar to those found at Kosovo. A study of the waste streams generated at Kosovo should aid U.S. plant designers in developing the process modifications and control schemes necessary to achieve U.S. standards of controls.

2.2 GASIFICATION PLANT SECTION DESCRIPTIONS

The Kosovo gasification plant sections which were selected for testing in Phase II are those which contain sources of potentially environmentally significant discharge streams. These sections include:

- Coal Preparation section,
- Gas Production section,
- Rectisol section,
- Tar/Oil Separation section,
- By-Product Storage section, and
- Flare System.

Each of these sections is described below.

2.2.1 Coal Preparation Section

In the coal preparation section, run-of-mine Kosovo coal is crushed, sized, and dried. The moisture content of the coal, as mined, is approximately 40-50% by weight. More than 50% of this moisture is removed by the Fleissner drying process to facilitate efficient operation of the Kosovo Lurgi-type gasifiers. A simplified flow diagram of the coal drying process is shown in Figure 2-5. Also shown are the sources of the major discharge streams generated in this section.

Run-of-mine coal is crushed and particles between 6 and 60 mm are stored in coal bunkers located above the Fleissner autoclaves. Over the coal bunker is a hooding system which is used to capture the coal particulates generated during coal transfer operations. Coal particules entrained in the air stream which is drawn through this hooding system are captured by a baghouse. The solids collected by the baghouse are sent to the power plant.

The Fleissner drying process uses saturated steam to heat the coal to a temperature of about 240°C (464°F) in an autoclave. One advantage of this process is that considerable quantities of moisture can be removed from the coal as liquid. This helps preserve the structural integrity of the coal matrix and minimizes fine generation during drying.

Kosovo Fleissner dryers operate in a batchwise manner. A complete drying cycle lasts from 160 to 200 minutes. The steps involved in the drying cycle are shown in Table 2-1. Throughout the drying cycle, small quantities of noncondensible gases (mostly CO_2) are bled from the autoclave. Before the autoclave is emptied, low pressure vent gases (mostly steam) are discharged through a vent into the atmosphere.

At Kosovo, the Fleissner autoclaves are arranged in groups of four so that blowdown steam and condensate from autoclaves being depressurized can be used to preheat the coal entering other autoclaves. Condensate from the drying process is used to satisfy in-plant water needs. Gases released from the condensate tank are discharged to the atmosphere.

The amount of moisture remaining in the coal after Fleissner treatment is primarily a function of the steam pressure used in the process. At Kosovo, the maximum stream pressure is about 3 MPa (30 atm). The moisture content of the dried coal is normally about 20-30% by weight.

Because the Fleissner operation is cyclic, discharges vary depending upon the step in the cycle. This characteristic makes it very difficult to determine representative discharge stream flow rates and compositions. The significant process and discharge streams in the Coal Preparation section are summarized in Table 2-2. Process wastes generated in this section were characterized by analyzing the autoclave vent and the condensate stream. Some of the environmental concerns in the Coal Preparation section are the quantity and composition of the volatile gases generated during the drying cycle and the character and quantity of pollutants in the condensate.

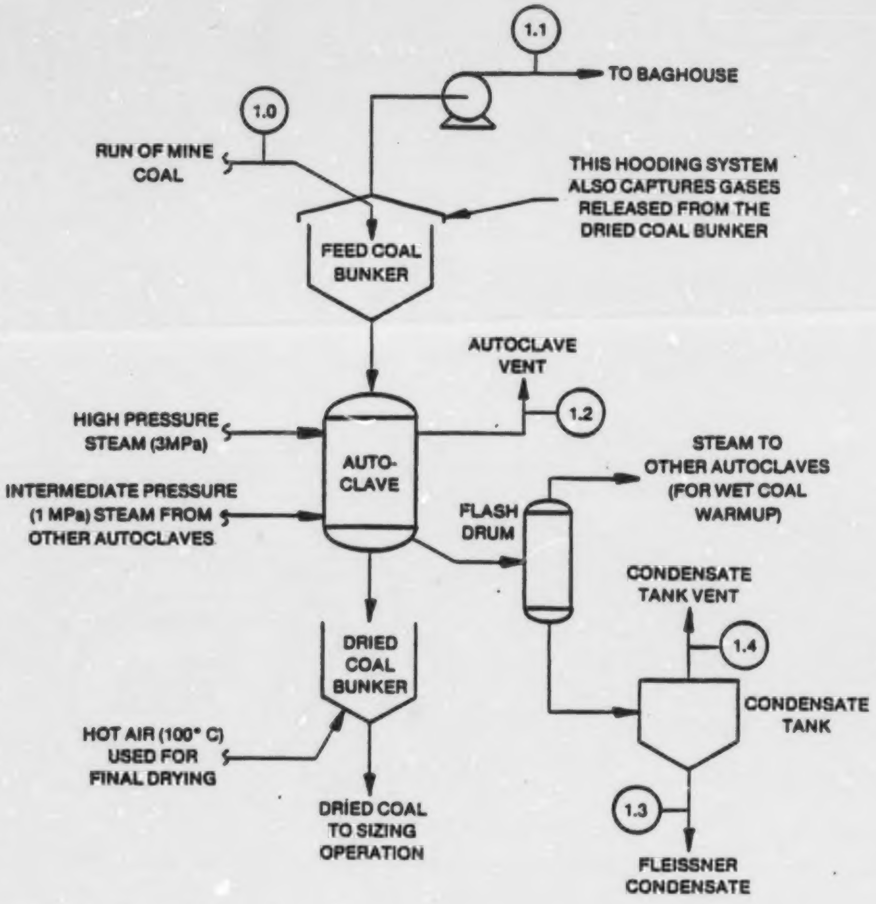

1.1
TO BAGHOUSE
1.0
RUN OF MINE COAL
THIS HOODING SYSTEM ALSO CAPTURES GASES RELEASED FROM THE DRIED COAL BUNKER
FEED COAL BUNKER
AUTOCLAVE VENT
1.2
HIGH PRESSURE STEAM (3MPa)
AUTO-CLAVE
INTERMEDIATE PRESSURE (1 MPa) STEAM FROM OTHER AUTOCLAVES
STEAM TO OTHER AUTOCLAVES (FOR WET COAL WARMUP)
FLASH DRUM
CONDENSATE TANK VENT
1.4
DRIED COAL BUNKER
CONDENSATE TANK
HOT AIR (100° C) USED FOR FINAL DRYING
DRIED COAL TO SIZING OPERATION
1.3
FLEISSNER CONDENSATE

Figure 2-5. Process flow diagram showing sampling points in the Kosovo Coal Drying section.

TABLE 2-1. FLEISSNER DRYING CYCLE

Step	Approximate Duration (minutes)
Coal Charging	10
1st Preheating (using low pressure, 1 MPa [10 atm] steam)	20
2nd Preheating (using intermediate pressure steam)	20
Final Heating (using high pressure, 3 MPa [30 atm] steam)	60
1st Autoclave Discharge (release of intermediate pressure steam)	20
2nd Autoclave Discharge (release of low pressure steam)	20
Emptying the Autoclave	10
TOTAL	160

TABLE 2-2. SIGNIFICANT PROCESS AND DISCHARGE STREAMS IN THE KOSOVO COAL PREPARATION SECTION

Stream Number	Stream Description	Stream[1] Type	Design[2] Flow Rate	Best Value[2,3] Flow Rate	Comments
1.0	Run-of-mine Coal	s	24,000	ND[4]	Sampled in Phase II
1.1 A	Fleissner Baghouse Gases	g	Unknown	ND	Not sampled in Phase II; mainly air
1.1 B	Fleissner Baghouse Catch	s	Unknown	ND	Sampled in Phase II; primarily coal particulate
1.2	Fleissner Autoclave Vent	g	Unknown	58	Sampled in Phase II; mainly steam, fixed gases, and particulates
1.3	Fleissner Condensate	aq	Unknown	ND	Sampled in Phase II
1.4	Condensate Tank Vent	g	Unknown	ND	Not sampled during Phase II; composition similar to that of Stream 1.2

[1] s - solid
aq - aqueous
g - gaseous

[2] Dry gas flow rate in m^3/gasifier-hr at 25°C, solid flow rate in kg/gasifier-hr

[3] See Appendix A for discussion of best value determination

[4] ND - Not determined

2.2.2 Gas Production Section

In the Gas Production section, the following functions are accomplished:

- the dried coal is gasified to produce crude product gas;
- the crude product gas is cooled and scrubbed to remove entrained coal fines and heavy organics; and
- the ash is removed from the gasifier and quenched.

A simplified process flow diagram for this section is shown in Figure 2-6. Also shown are the section's discharge sources.

There are six pressurized fixed-bed, oxygen-blown, Lurgi-type gasifiers at Kosovo. Dried coal is fed by conveyor belts to coal bunkers located above each gasifier. Nitrogen is used as a purge gas for each bunker to prevent spontaneous ignition of the coal. The coal bunker purge gases are collected in hoods and sent through a scrubber to remove entrained coal dust before being discharged to the atmosphere. The blowdown liquid from the coal bunker vent gas is combined with other wastewaters generated in this section prior to discharge (Stream 12.3).

The operating cycle of a Lurgi-type coal feed lock hopper consists of four steps:

- filling the hopper with coal,
- pressurizing the coal lock,
- feeding the coal to the gasifier, and
- depressurizing the coal lock.

Coal enters the coal lock from the coal bunker through a transition section which is referred to as a coal lock bucket. Gases displaced by the coal during the charging cycle are vented to the atmosphere through the coal lock bucket vent (Stream 3.1). When the coal lock bucket vent becomes plugged with coal dust and tar, as it was during Phases I and II of the test program, these gases are released through the low pressure coal lock vent (Stream 3.2).

After the coal lock if filled with coal, it is pressurized with crude product gas. When the coal lock has reached operating pressure, the valve separating the coal lock from the gasifier is opened and coal enters the gasifier from the coal lock.

When all the coal in the lock hopper has been added to the gasifier, the valve separating the coal lock from the gasifier is closed and the coal lock is depressurized. In the initial stages of coal lock depressurization, high pressure gas is sent to the flare system (Stream 3.6). Then, after the gas pressure in the coal lock has been reduced to around 0.2 MPa (2 atm), residual lock gases are vented directly to the atmosphere (Stream 3.2).

Steam and oxygen injected at the bottom of each gasifier react with the coal to produce a hot, crude product gas. This gas exits the top of each

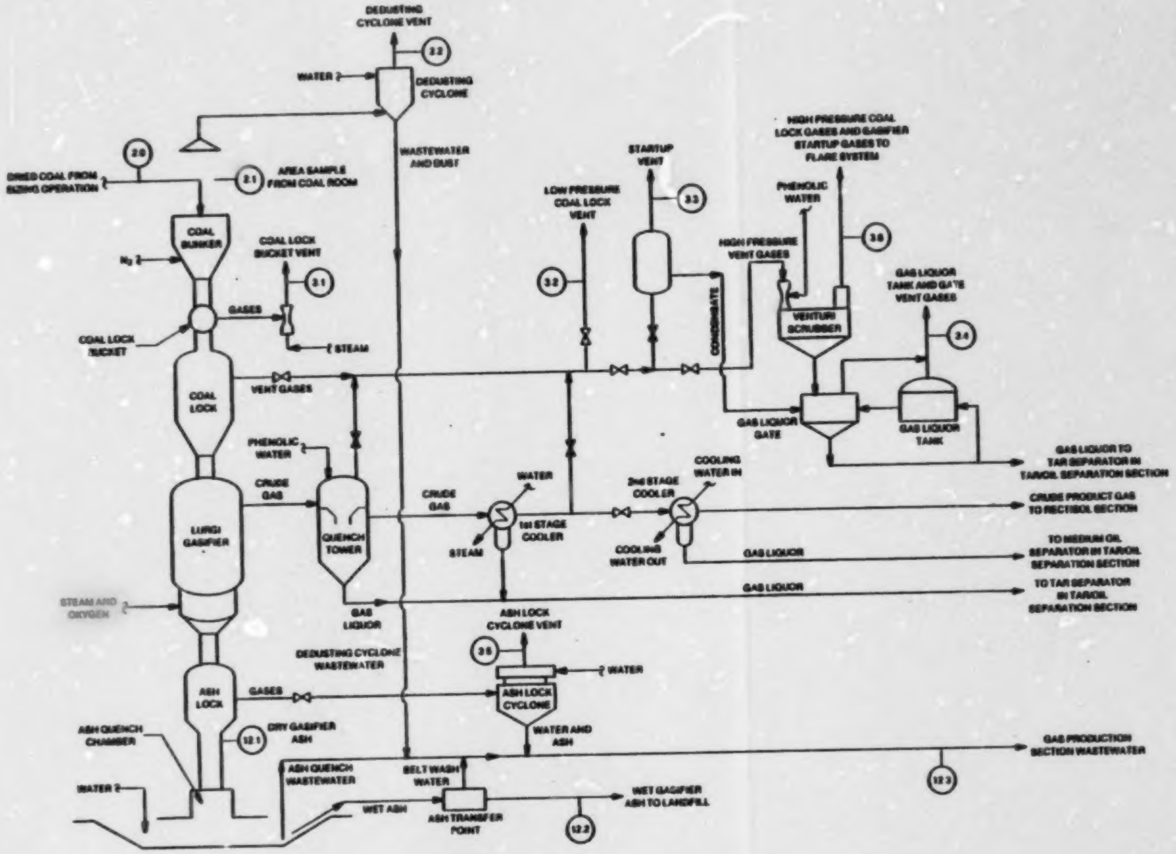

DEDUSTING CYCLONE VENT
2.2
WATER
DEDUSTING CYCLONE
WASTEWATER AND DUST
2.0
DRIED COAL FROM SIZING OPERATION
2.1
AREA SAMPLE FROM COAL ROOM
COAL BUNKER
N_2
COAL LOCK BUCKET VENT
3.1
GASES
STEAM
COAL LOCK BUCKET
COAL LOCK
VENT GASES
PHENOLIC WATER
CRUDE GAS
LURGI GASIFIER
QUENCH TOWER
STEAM AND OXYGEN
GAS LIQUOR
DEDUSTING CYCLONE WASTEWATER
ASH LOCK
GASES
DRY GASIFIER ASH
12.1
ASH QUENCH CHAMBER
WATER
ASH QUENCH WASTEWATER
WET ASH
BELT WASH WATER
ASH TRANSFER POINT
12.2
WET GASIFIER ASH TO LANDFILL
CRUDE GAS
WATER
1st STAGE COOLER
STEAM
ASH LOCK CYCLONE VENT
3.5
WATER
ASH LOCK CYCLONE
WATER AND ASH
LOW PRESSURE COAL LOCK VENT
3.2
STARTUP VENT
3.3
CONDENSATE
HIGH PRESSURE VENT GASES
PHENOLIC WATER
HIGH PRESSURE COAL LOCK GASES AND GASIFIER STARTUP GASES TO FLARE SYSTEM
3.6
VENTURI SCRUBBER
GAS LIQUOR TANK AND GATE VENT GASES
3.4
GAS LIQUOR GATE
GAS LIQUOR TANK
2nd STAGE COOLER
COOLING WATER IN
COOLING WATER OUT
GAS LIQUOR
GAS LIQUOR
GAS LIQUOR TO TAR SEPARATOR IN TAR/OIL SEPARATION SECTION
CRUDE PRODUCT GAS TO RECTISOL SECTION
TO MEDIUM OIL SEPARATOR IN TAR/OIL SEPARATION SECTION
TO TAR SEPARATOR IN TAR/OIL SEPARATION SECTION
GAS PRODUCTION SECTION WASTEWATER
12.3

Figure 2-6. Process flow diagram showing sampling points in the Kosovo Gas Production section.

gasifier and is quenched directly with water. The gas is then cooled further in a series of indirect heat exchangers. After cooling, the gas is routed to the Rectisol section for purification. Condensed organic liquids and process condensate generated during the quenching and cooling processes are sent to the Tar/Oil Separation section.

Hot ash generated during gasification is collected from the bottom of each gasifier in a lock hopper. This ash is water-quenched and discharged (along with power plant ash) to a landfill. Ash quench blowdown water is combined with the coal bunker scrubber blowdown and discharged (Stream 12.3). Ash lock expansion gases are routed through a water-washed cyclone to remove entrained particulate matter. These gases are then discharged to the atmosphere (Stream 3.5). The wastewater and ash discharged from this cyclone are combined with the two previously mentioned wastewater streams and discharged (Stream 12.3).

The startup of a gasifier normally requires approximately eight hours. During the initial stages of startup, the gases generated are vented directly to the atmosphere (Stream 3.3). Later in the startup sequence, when a combustible gas is being produced, the gas is routed to the flare system (Stream 3.6).

The significant process and discharge streams in the Gas Production section are given in Table 2-3. The dedusting cyclone vent (Stream 2.2) contains particulates which are of concern although the gas itself is primarily air. Streams 3.2, 3.3, and 3.6 are all very difficult to characterize because the coal lock depressurization and gasifier startup processes are periodic and variable. The coal lock bucket vent (Stream 3.1) was not found to be significant due to plugging of the vent. Gases normally vented through this line were being released through the low pressure coal vent during the Phase II testing program.

Because of its high flow rate, the ash leaving the gasifier is potentially an environmentally significant discharge stream. The main problem associated with disposal of the ash is the potential for soluble pollutants to be leached from the ash in the landfill.

2.2.3 Rectisol Section

In the Rectisol section, acid gases such as H_2S, CO_2, and HCN are removed from the product gas. A process flow diagram for the Rectisol section is presented in Figure 2-7.

Cooled crude product gas (Stream 7.3) at about 22°C (72°F) and 2.3 MPa (23 atm) enters the Rectisol section from the Gas Production section. The gas is then cooled further by washing with cold water followed by cold methanol. Condensed liquids generated during this cooling include an organic phase (naphtha) and an aqueous phase. The naphtha (Stream 7.6) is sent to the By-Product Storage section while the aqueous stream (Stream 7.5) is sent to the Tar/Oil Separation section.

TABLE 2-3. SIGNIFICANT PROCESS AND DISCHARGE STREAMS IN KOSOVO GAS PRODUCTION SECTION

Stream Number	Stream Description	Stream[1] Type	Design[2] Flow Rate	Best Value[2,3] Flow Rate	Comments
2.0	Dried Coal	s	16,000	ND[4]	Sampled in Phase II
2.1	Coal Room Gases	g	Unknown	ND	Sampled in Phase II; Primarily Coal Dust
2.2	Dedusting Cyclone Vent	g	4,400	7,200	Sampled in Phase II; Mainly Air with Coal Particulate
3.1	Coal Lock Bucket Vent	g	28	ND	Sampled in Phase II; Normally Plugged
3.2	Low Pressure Coal Lock Vent	g	39	33	Sampled in Phase II; Similar to Crude Product Gas; Contains Particulate
3.3	Gasifier Start-up Vent	g	Unknown	Variable	Sampled in Phase II; Varies with Time
3.4	Gas Liquor Tank Vent	g	Unknown	44	Not Sampled in Phase II; Composition similar to that of Stream 13.7
3.5	Ash Lock Cyclone Vent	g	31	71	Sampled in Phase II; Mainly Stream, O_2, and Fixed Gases
3.6	High Pressure Coal Lock Vent	g	380	230	Sampled in Phase II; Mainly Fixed Gases and Particulate
12.1	Dry Gasifier Ash	s	2,700	ND	Sampled in Phase II
12.2	Wet Gasifier Ash	s	> 2,700	ND	Not Sampled in Phase II
12.3	Quenched Ash Wastewater	aq	3	ND	Not Sampled in Phase II

[1] g - gaseous
aq - aqueous
s - solid

[2] All dry gas flow rates in m^3/gasifier-hr at 25°C; aqueous flow rates in m^3/gasifier-hr; solid flow rates in kg/gasifier-hr

[3] See Appendix A for discussion of best value determination

[4] ND - Not Determined

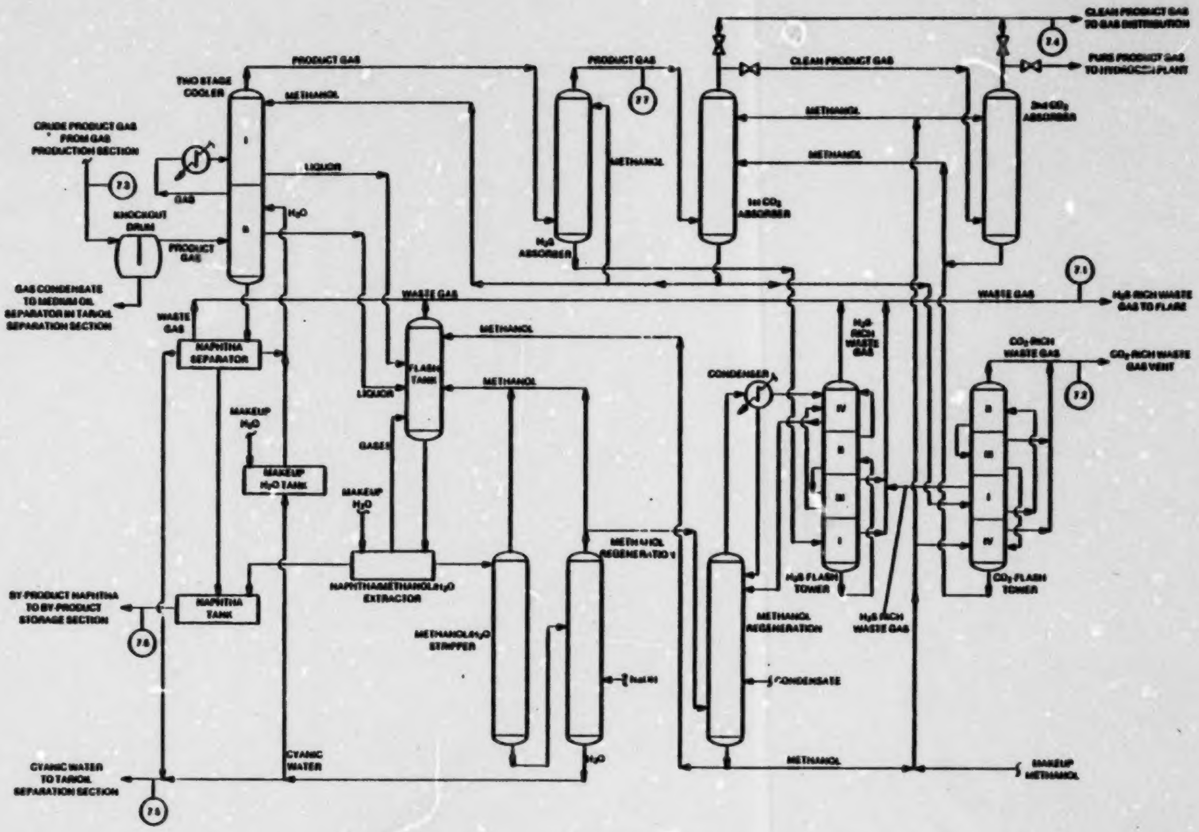

CRUDE PRODUCT GAS
FROM GAS
PRODUCTION SECTION
7.3
KNOCKOUT
DRUM
PRODUCT
GAS
GAS CONDENSATE
TO MEDIUM OIL
SEPARATOR IN TAR/OIL
SEPARATION SECTION
TWO STAGE
COOLER
I
II
GAS
H2O
PRODUCT GAS
METHANOL
LIQUOR
WASTE
GAS
NAPHTHA
SEPARATOR
MAKEUP
H2O
MAKEUP
H2O TANK
BY-PRODUCT NAPHTHA
TO BY-PRODUCT
STORAGE SECTION
7.6
NAPHTHA
TANK
CYANIC WATER
TO TAR/OIL
SEPARATION SECTION
7.5
CYANIC
WATER
WASTE GAS
FLASH
TANK
LIQUOR
GASES
MAKEUP
H2O
NAPHTHA/METHANOL/H2O
EXTRACTOR
METHANOL
METHANOL
METHANOL/H2O
STRIPPER
METHANOL
REGENERATION
H2O
PRODUCT GAS
7.7
METHANOL
H2S
ABSORBER
1st CO2
ABSORBER
CLEAN PRODUCT GAS
METHANOL
METHANOL
2nd CO2
ABSORBER
CLEAN PRODUCT GAS
TO GAS DISTRIBUTION
7.4
PURE PRODUCT GAS
TO HYDROGEN PLANT
WASTE GAS
7.1
H2S RICH WASTE
GAS TO FLARE
H2S
RICH
WASTE
GAS
CONDENSER
IV
II
III
I
H2S FLASH
TOWER
METHANOL
REGENERATION
CONDENSATE
H2S RICH
WASTE GAS
CO2 RICH
WASTE GAS
CO2 RICH WASTE
GAS VENT
7.2
II
III
I
IV
CO2 FLASH
TOWER
METHANOL
MAKEUP
METHANOL

Figure 2-7. Process flow diagram showing sampling points in the Kosovo Rectisol section.

After cooling, the crude product gas is scrubbed with cold methanol in the H_2S absorber. H_2S-rich waste gas (Stream 7.1) is released from the H_2S-rich methanol during the methanol regeneration process and is routed to the flare system.

The H_2S-lean product gas goes to two CO_2 absorbers. In these columns the bulk of the CO_2 remaining in the product gas is absorbed by a wash of CO_2-lean methanol. The overhead gas from the first CO_2 absorber is fed directly into the fuel gas distribution system. The second CO_2 absorber is used to remove additional CO_2 whenever 'pure' product gas is needed for feed to the cryogenic hydrogen separation unit.

The significant process and environmental discharge streams in the Rectisol section are given in Table 2-4. The H_2S-rich waste gas (Stream 7.1) is particularly significant. The high sulfur species content and high flow rate of this stream make it a significant control problem. At Kosovo, the CO_2-rich waste gas (Stream (7.2) is vented directly to the atmosphere. U.S. standards will probably require some control of this discharge stream to restrict the emission of hydrocarbons, carbon monoxide and sulfur species.

2.2.4 Tar/Oil Separation Section

In the Tar/Oil Separation section, heavy tar, light tar, and medium oil are separated from the plant's condensed gas liquor streams. A series of phase separators are used to remove these organic fractions from the incoming condensate streams. A process flow diagram for this section is shown in Figure 2-8.

The light tar and medium oil by-products separated from the inlet gas liquor streams are sent to the By-product Storage section, while the aqueous phase from the phase separators is sent to the Phenosolvan section for further treatment. A sludge consisting primarily of heavy tar and coal dust is sent to a landfill (Stream 13.8).

Significant process and discharge streams in the Tar/Oil Separation section are given in Table 2-5. There are six tank vents discharging directly to the atmosphere (Streams 13.1, 13.5, and 13.7). Expansion and waste gases (Stream 13.6) are sent to the flare system.

2.2.5 Phenosolvan Section

In the Phenosolvan section, phenolic water from the Tar/Oil Separation section is treated to remove residual tars and oils, dissolved gases (principally ammonia), and dissolved organics (principally phenols). A process flow diagram of the Phenosolvan section is shown in Figure 2-9.

The phenolic water enters the Phenosolvan section through a degassing cyclone where dissolved gases are released and vented to the atmosphere. The water is then routed through a storage tank/gravity separator, and a series of

TABLE 2-4. SIGNIFICANT PROCESS AND DISCHARGE STREAMS IN KOSOVO RECTISOL SECTION

Stream Number	Stream Description	Stream[1] Type	Design[2] Flow Rate	Best Value[2,3] Flow Rate	Comments
7.1	H_2S-Rich-Waste Gas	g	2,700	3,600	Sampled in Phase II; Mainly CO_2, H_2S, NH_3
7.2	CO_2-Rich Vent Gas	g	2,400	3,600	Sampled in Phase II; Mainly CO_2
7.3	Crude Product Gas	g	18,800	ND[4]	Sampled in Phase II; Mainly Fixed Gases With H_2S and HCN
7.4	Clean Product Gas	g	13,100	ND	Sampled in Phase II; Mainly Fixed Gases
7.5	Cyanic Water	aq	0.8	ND	Sampled in Phase II
7.6	By-Product Naphtha	ol	130	ND	Sampled in Phase II at Sample Point 15.3B
7.7	Intermediate Process Gas	g	16,300	ND	Sampled in Phase II; Mainly Fixed Gases

[1] g - gaseous
aq - aqueous
ol - organic liquid

[2] All dry gas flow rates in m^3/gasifier-hr at 25°C; aqueous flow rate in m^3/gasifier-hr, organic liquid flow rates in kg/gasifier-hr

[3] See Appendix A for discussion of best value determination

[4] ND - Not determined

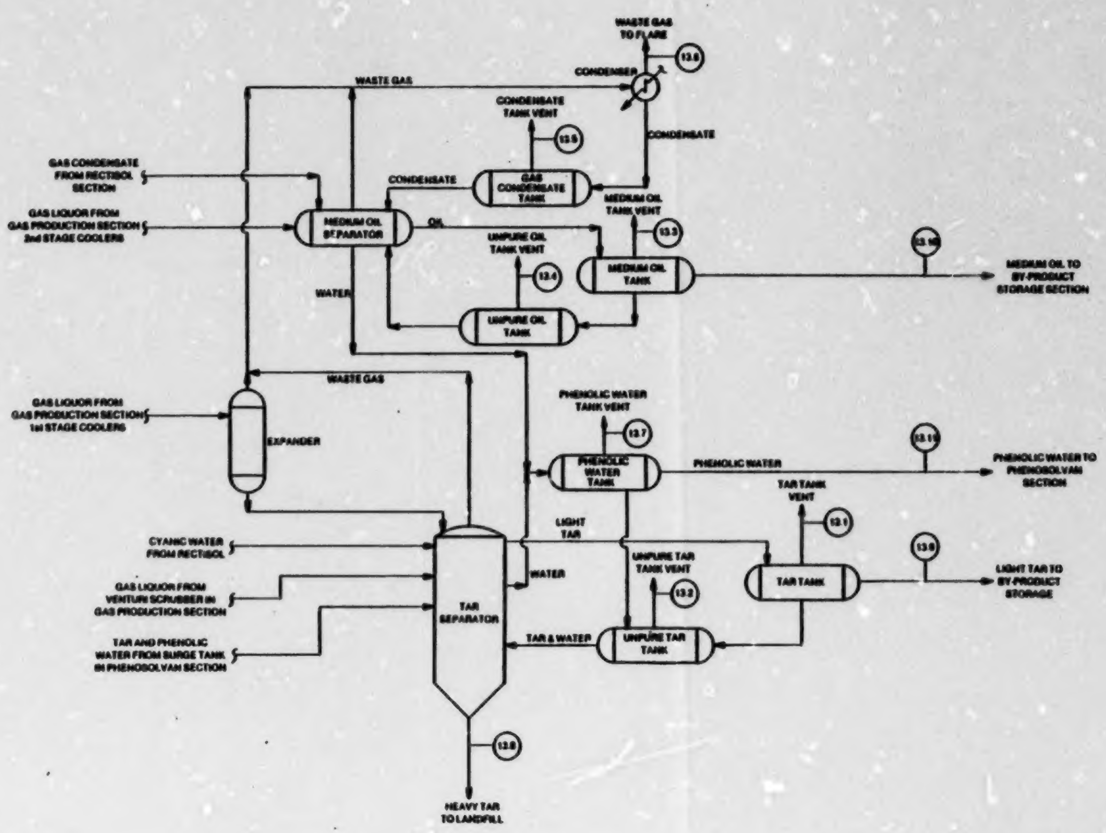

WASTE GAS TO FLARE
13.6
CONDENSER
WASTE GAS
CONDENSATE TANK VENT
13.5
CONDENSATE
GAS CONDENSATE FROM RECTISOL SECTION
GAS LIQUOR FROM GAS PRODUCTION SECTION 2nd STAGE COOLERS
MEDIUM OIL SEPARATOR
CONDENSATE
GAS CONDENSATE TANK
MEDIUM OIL TANK VENT
13.3
OIL
UNPURE OIL TANK VENT
13.4
MEDIUM OIL TANK
13.10
MEDIUM OIL TO BY-PRODUCT STORAGE SECTION
WATER
UNPURE OIL TANK
WASTE GAS
GAS LIQUOR FROM GAS PRODUCTION SECTION 1st STAGE COOLERS
EXPANDER
PHENOLIC WATER TANK VENT
13.7
PHENOLIC WATER TANK
PHENOLIC WATER
13.11
PHENOLIC WATER TO PHENOSOLVAN SECTION
TAR TANK VENT
13.1
LIGHT TAR
CYANIC WATER FROM RECTISOL
WATER
UNPURE TAR TANK VENT
13.9
TAR TANK
LIGHT TAR TO BY-PRODUCT STORAGE
GAS LIQUOR FROM VENTURI SCRUBBER IN GAS PRODUCTION SECTION
TAR SEPARATOR
13.2
TAR AND PHENOLIC WATER FROM SURGE TANK IN PHENOSOLVAN SECTION
TAR & WATER
UNPURE TAR TANK
13.8
HEAVY TAR TO LANDFILL

Figure 2-8. Process flow diagram showing sampling points in the Kosovo Tar/Oil separation section.

TABLE 2-5. SIGNIFICANT PROCESS AND DISCHARGE STREAMS IN KOSOVO TAR/OIL SEPARATION SECTION

Stream Number	Stream Description	Stream[1] Type	Design[2] Flow Rate	Best Value[2,3] Flow Rate	Comments
13.1	Tar Tank Vent	g	>0.44	0.51	Sampled in Phase II; Mainly air and fixed gases
13.2	Unpure Tar Tank Vent	g	Negligible	ND[4]	Not Sampled in Phase II; Mainly air
13.3	Medium Oil Tank Vent	g	0.27	1.7	Sampled in Phase II; Mainly Acid Gases and Methane
13.4	Unpure Oil Tank Vent	g	Negligible	ND	Not Sampled in Phase II; Mainly Air
13.5	Condensate Tank Vent	g	Unknown	3.4	Sampled in Phase II; Mainly Fixed Gases
13.6	Waste Gas to Flare	g	28	ND	Sampled in Phase II; Mainly Fixed Gases, Hydrocarbons, and Sulfur Species
13.7	Phenolic Water Tank Vent	g	>14	5.5	Sampled in Phase II; Mainly Water, Fixed Gases
13.8	Heavy Tar and Dust	s	100	ND	Sampled in Phase II for Trace Elements, PMA's
13.9	Light Tar By-Product	ol	400	ND	Sampled in Phase II
13.10	Medium Oil By-Product	ol	250	ND	Sampled in Phase II
13.11	Phenolic Water	aq	ND	ND	Sampled in Phase II at Sample Point 14.0

[1] g - gaseous
aq - aqueous
ol - organic liquid
s - solid

[2] All dry gas flow rates in m^3/gasifier-hr at 25°C; aqueous flow rates in m^3/gasifier-hr; organic liquid and heavy tar flow rates in kg/gasifier-hr

[3] See Appendix A for discussion of best value determination

[4] ND - Not determined

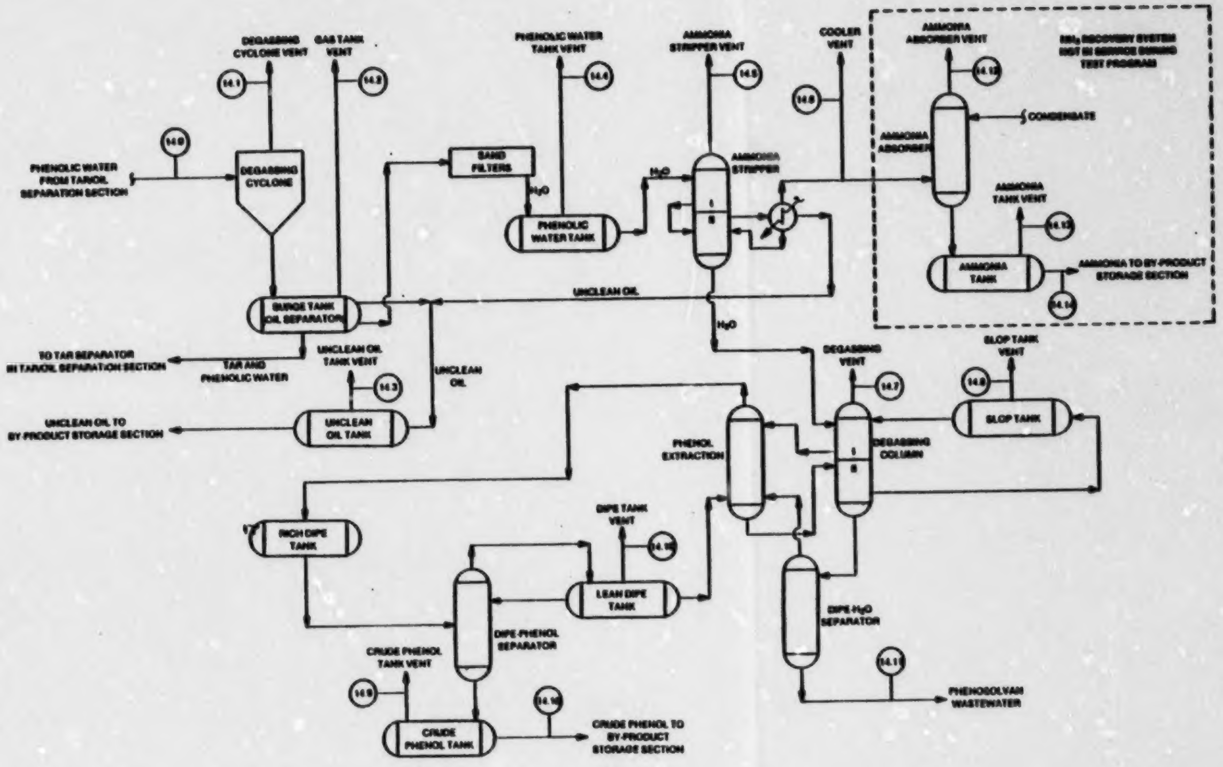

PHENOLIC WATER FROM TAROIL SEPARATION SECTION
14.0
DEGASSING CYCLONE
DEGASSING CYCLONE VENT
14.1
GAS TANK VENT
14.2
SURGE TANK OIL SEPARATOR
TO TAR SEPARATOR IN TAROIL SEPARATION SECTION
TAR AND PHENOLIC WATER
UNCLEAN OIL TANK VENT
14.3
UNCLEAN OIL TANK
UNCLEAN OIL TO BY PRODUCT STORAGE SECTION
UNCLEAN OIL
SAND FILTERS
H_2O
PHENOLIC WATER TANK VENT
14.4
PHENOLIC WATER TANK
UNCLEAN OIL
H_2O
AMMONIA STRIPPER VENT
14.5
AMMONIA STRIPPER
COOLER VENT
14.6
H_2O
AMMONIA ABSORBER VENT
14.12
AMMONIA ABSORBER
CONDENSATE
NH_3 RECOVERY SYSTEM NOT IN SERVICE DURING TEST PROGRAM
AMMONIA TANK VENT
14.13
AMMONIA TANK
AMMONIA TO BY-PRODUCT STORAGE SECTION
14.14
DEGASSING VENT
14.7
DEGASSING COLUMN
SLOP TANK VENT
14.8
SLOP TANK
PHENOL EXTRACTION
RICH DIPE TANK
DIPE TANK VENT
14.15
LEAN DIPE TANK
DIPE-PHENOL SEPARATOR
CRUDE PHENOL TANK VENT
14.9
CRUDE PHENOL TANK
14.10
CRUDE PHENOL TO BY-PRODUCT STORAGE SECTION
DIPE-H_2O SEPARATOR
14.11
PHENOSOLVAN WASTEWATER

Figure 2-9. Process flow diagram showing sampling points in the Kosovo Phenosolvan section.

sand filters to remove residual tars and oils. Oils collected from the surface of the stored wastewater are sent to the By-Product Storage section while the tars and filter backwash water are returned to the Tar/Oil Separation section.

After removal of residual tars and oils, the phenolic water is heated and fed to two degassing columns. In these columns, dissolved gases such as NH_3, CO_2, and H_2S are steam-stripped from the water. According to the Kosovo process design, the ammonia removed in this process is supposed to be collected as a by-product and sent to the By-Product Storage section. However, during the Phase II test program, this ammonia was not being recovered but was being discharged directly to the atmosphere through the ammonia stripper vent (Stream 14.5).

The phenol-rich water leaving the degassing columns is routed through a series of heat exchangers and then through extraction columns to remove phenols by extraction with diisopropylether (DIPE). The phenol-rich DIPE is thermally regenerate by distillation, producing lean DIPE which is recycled to the Extraction section. The crude phenols which are separated from the DIPE during the regeneration process are sent to the By-Product Storage section.

Significant process and discharge streams for the Phenoslvan section are given in Table 2-6. There are twelve gaseous discharge vents in this section. The vent of primary concern is the ammonia stripper vent (14.5).

2.2.6 By-Product Storage Section

The By-Product Storage section is designed to store the liquid by-products generated in the Tar/Oil Separation, Phenosolvan, and Rectisol sections. The by-products stored in this section are light tar, medium oil, naphtha, crude phenol, and unclean oil. By-product NH_4OH is also supposed to be stored in this section; however, this by-product was not being recovered during the test program. A process flow diagram of the By-Product Storage section is shown in Figure 2-10.

There are six discharge sources in the By-Product Storage section. All of these sources are tank vents discharging vapors to the atmosphere. Table 2-7 shows these By-Product Storage section discharge streams.

2.2.7 Flare System

The flare system is used to burn some of the gasification plant's most significant discharge streams. Streams routed to the flare are:

- high pressure coal lock expansion gases from the Gas Production section (Stream 3.6),
- gasifier startup gases from the Gas Production section (Stream 3.6),
- H_2S-rich waste gas from the Rectisol section (Stream 7.1), and
- expansion and waste gases generated in the Tar/Oil Separation section (Stream 13.6).

TABLE 2-6. SIGNIFICANT PROCESS AND DISCHARGE STREAMS IN KOSOVO PHENOSOLVAN SECTION

Stream Number	Stream Description	Stream[1] Type	Design[2] Flow Rate	Best Value[2,3] Flow Rate	Comments
14.0	Phenosolvan Inlet Water (Phenolic Water)	aq	>13	ND	Sampled in Phase II
14.1	Degassing Cyclone Vent	g	2.2	ND[4]	Not Sampled in Phase II; Contains H_2S, Acid Gases
14.2	Gas Tank Vent	g	ND	ND	Not Sampled in Phase II; Mainly Air
14.3	Unclean Oil Tank Vent	g	ND	ND	Not Sampled in Phase II; Mainly Air
14.4	Phenolic Water Tank Vent	g	ND	ND	Not Sampled in Phase II; Mainly Air
14.5	Ammonia Stripper Vent	g	9.8	160	Sampled in Phase II; Mainly H_2O, H_2, NH_3 CO_2, H_2S, HCN
14.6	Cooler Vent	g	4.4	ND	Not Sampled in Phase II; High NH_3 Content; Similar to 14.5
14.7	Second Degassing Vent	g	0.4	ND	Not Sampled in Phase II; Mainly Air
14.8	Slop Tank Vent	g	Unknown	ND	Not Sampled in Phase II; Mainly Air
14.9	Crude Phenol Tank Vent	g	0.09	0.20	Not Sampled in Phase II; Mainly Air
14.10	DIPE Tank Vent	g	0.5	ND	Not Sampled in Phase II; Mainly Air
14.11	Wastewater	aq	13	ND	Sampled in Phase II; This Stream is Discharged
14.12	NH_3 Absorber Vent	g	Unknown	ND	Not Used During Test Program
14.13	NH_3 Storage Tank Vent	g	Unknown	ND[4]	Not Used During Test Program
14.14	NH_4OH By-Product	aq	200	ND	Not Used During Test Program
14.15	Unclean Oil (to By-Product Storage)	ol	300	ND	Not Sampled in Phase II; Similar to Medium Oil By-Product
14.16	Crude Phenols (to By-Product Storage)	ol	90	ND	Not Sampled in Phase II

[1] g - gaseous
aq - aqueous
ol - organic liquid

[2] All dry gas flow rates in m^3/gasifier-hr at 25°C, aqueous flow rates in m^3/gasifier-hr, by-product flow rates in kg/gasifier-hr

[3] See Appendix A for a discussion of best value determination

[4] ND - Not determined

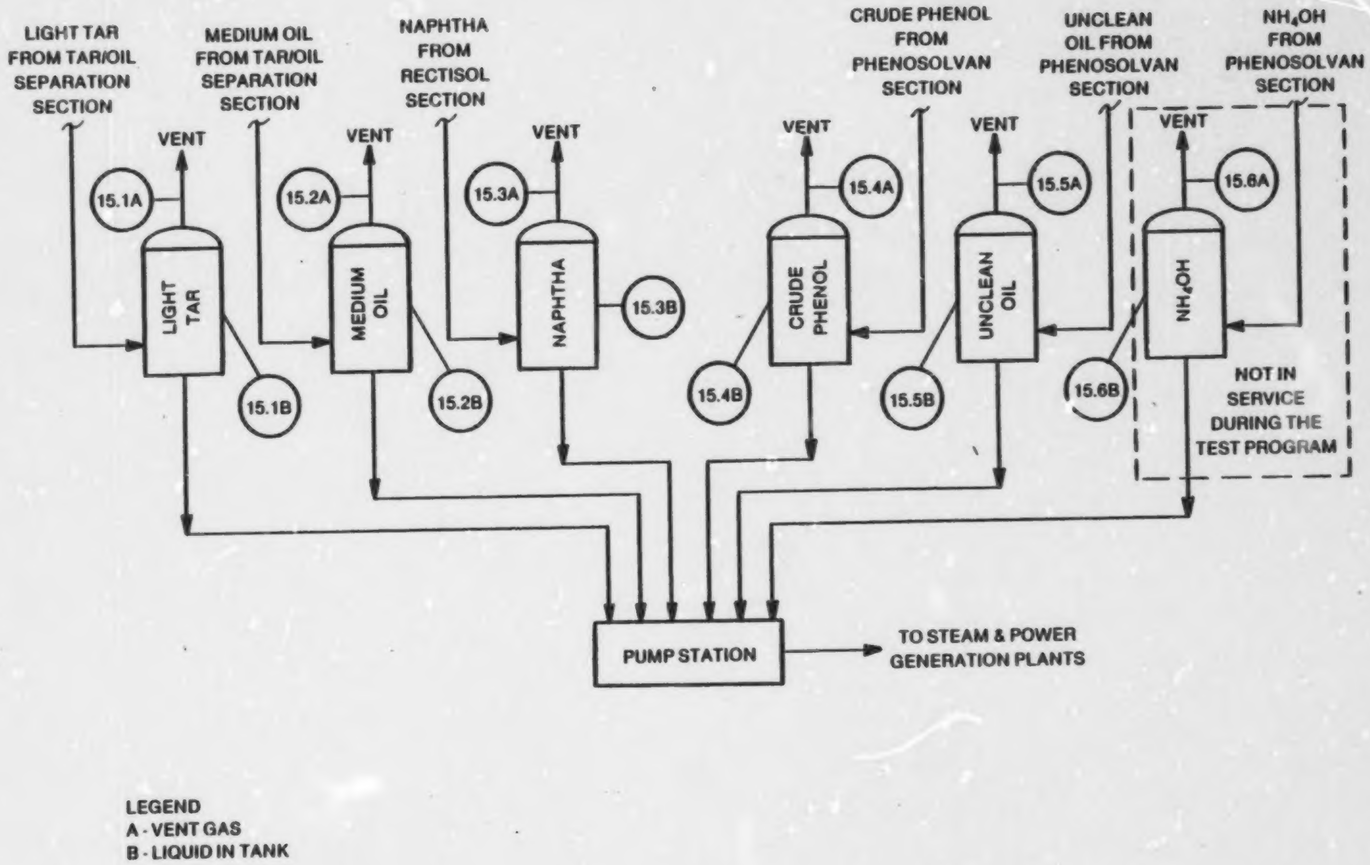

LIGHT TAR FROM TAR/OIL SEPARATION SECTION
MEDIUM OIL FROM TAR/OIL SEPARATION SECTION
NAPHTHA FROM RECTISOL SECTION
CRUDE PHENOL FROM PHENOSOLVAN SECTION
UNCLEAN OIL FROM PHENOSOLVAN SECTION
NH₄OH FROM PHENOSOLVAN SECTION
VENT
VENT
VENT
VENT
VENT
VENT
15.1A
15.2A
15.3A
15.4A
15.5A
15.6A
LIGHT TAR
MEDIUM OIL
NAPHTHA
CRUDE PHENOL
UNCLEAN OIL
NH₄OH
15.1B
15.2B
15.3B
15.4B
15.5B
15.6B
NOT IN SERVICE DURING THE TEST PROGRAM
PUMP STATION
TO STEAM & POWER GENERATION PLANTS
LEGEND
A - VENT GAS
B - LIQUID IN TANK

Figure 2-10. Process flow diagram showing sampling points in the Kosovo By-Product Storage section.

TABLE 2-7. SIGNIFICANT PROCESS AND DISCHARGE STREAMS IN KOSOVO BY-PRODUCT STORAGE SECTION

Stream Number	Stream Description	Stream[1] Type	Design[2] Flow Rate	Best Value[2,3] Flow Rate	Comments
15.1	Light Tar Storage Tank Vent	g	0.55	ND[4]	Not Sampled in Phase II; Composition Similar to that of Stream 13.1
15.2	Medium Oil Storage Tank Vent	g	0.27	ND	Not Sampled in Phase II; Composition Similar to that of Stream 13.3
15.3	Naphtha Storage Tank Vent	g	0.14	4.5	Sampled in Phase II; Mainly Air and Aromatic Hydrocarbons
15.4	Crude Phenol Storage Tank Vent	g	0.09	ND	Not Sampled in Phase II; Mainly Air
15.5	Unclean Oil Storage Tank Vent	g	0.03	ND	Not Sampled in Phase II; Composition Similar to that of Stream 13.3
15.6	NH_4OH Storage Tank Vent	g	0.22	-	Not in Use During Testing Program

[1] g - gaseous

[2] All dry gas flow rates in m^3/gasifier-hr at 25°C

[3] See Appendix A for discussion of best determination

[4] ND - Not determined

SECTION 3

RATIONALE FOR PHASE II TESTING

The purpose of the Kosovo test program was to obtain representative data on the potential environmental impacts of uncontrolled Lurgi-type gasification technology. The data obtained from the Kosovo program may be used to aid in the design of process modifications and control schemes for U.S. Lurgi facilities. For each phase of the program, a test plan was developed so that the sampling and analytical work performed could achieve that phase's objectives. This section presents the rationale used to develop the Phase II test plan.

The primary objectives for this phase of the program were:

- to verify and supplement the Phase I test results, and
- to identify and measure trace pollutants, both organic and inorganic, in the plant's discharge streams.

3.1 PLANT SECTION SELECTION

The gasification plant sections selected for study were those considered to be an essential part of Lurgi system and/or those which contained discharge sources unique to the process of gasifying coal. Based on these criteria, the following plant sections were included in the Phase II test plan:

- Coal Preparation,
- Gas Production,
- Rectisol (Acid Gas Removal)
- Tar/Oil Separation,
- Phenosolvan,
- By-Product Storage, and
- Flare System.

The Kosovo plant sections not studied in Phase II along with reasons for omissions are listed below:

Steam Plant;	section contained no waste streams unique to Lurgi gasification systems.
Inlet Water Treatment;	section contained no waste streams unique to Lurgi gasification systems.
Cooling Water System;	section contained no waste streams unique to Lurgi gasification systems.
Process Wastewater Treatment;	Facilities not in service.
Oxygen Plant;	section was not a direct source of major discharge or by-product streams.

Product Gas Distribution;	section was not a direct source of major discharge or by-product streams.

3.2 STREAM SELECTION

Engineering judgment, pretest screening results, and the Phase I test results were used to select the streams from which information relevant to the Phase II objectives could be gathered.

In general, a stream was selected for testing for one or more of the following four reasons:

- a high discharge rate,
- a significant pollutant concentration,
- contributed to the trace pollutant characterization, or
- provided useful process information.

The streams which were selected for testing in Phase II are shown in Table 3-1.

3.2.1 High Discharge Rate

Discharge and flare feed streams which were found in Phase I or determined from plant design to have a significant rate of discharge were selected for testing. For example, the CO_2-rich waste gas design flow rate is 2400 m^3/gasifier-hr at 25°C. This makes this stream one of the largest in the plant. Even a low concentration of a pollutant in this stream could be significant. Therefore, it was included in the Phase II study. Streams were also included if the quantities of entrained particulates discharged with the streams were likely to be significant. The dedusting cyclone vent gas is one example.

3.2.2 Significant Pollutant Concentration

Some discharge and flare feed streams were likely to impact the environment even at low discharge rates. This criterion allowed a stream to be selected based on the 'quality' of its discharge. For the purposes of this test program, the SAM/1A multimedia environmental goals (see Section 5.0) were used as a guideline for analyzing severity of a stream component.

An example of a stream selected on this basis is the naphtha storage tank vent gas. Phase I test results indicated that the concentration of aromatic hydrocarbons (primarily benzene and toluene) and mercaptans in the Naphtha storage tank vent gas were high. These compounds are considered to be potentially harmful pollutants.

TABLE 3-1. KOSOVO STREAMS SELECTED FOR PHASE II TESTING

Sample Point	Stream Name	Media	Reason for Selection: High Discharge Rate	Reason for Selection: Significant Pollutant Concentration	Reason for Selection: Trace Pollutant Characterization	Reason for Selection: Informational Value
Coal Preparation Section						
1.2	Fleissner Autoclave Vent	gaseous	X			
1.3	Fleisner Condensate	aqueous			X	
1.1	Fleissner Baghouse Catch	solid			X	
Gas Production Section						
2.2	Dedusting Cyclone Vent	gaseous	X			
3.2	Low Pressure Coal Lock Vent	gaseous		X	X	
3.3	Gasifier Startup Vent	gaseous		X		
3.6	High Pressure Coal Lock Vent	gaseous	X			
12.3	Quenched Ash Wastewater	aqueous	X		X	
2.0	Dried Coal	solid			X	X
2.1	Coal Room Dust	solid				X
12.1	Dry Gasifier Ash	solid			X	X
12.2	Wet Gasifier Ash	solid	X			

(Continued)

TABLE 3-1. (Continued)

Sample Point	Stream Name	Media	Reason for Selection: High Discharge Rate	Significant Pollutant Concentration	Trace Pollutant Characterization	Informational Value
Rectisol Section						
7.1	H_2S-Rich Waste Gas	gaseous	X	X	X	
7.2	CO_2-Rich Waste Gas	gaseous	X		X	
7.3	Crude Product Gas	gaseous			X	X
7.4	Clean Product Gas	gaseous			X	X
7.7	Intermediate Process Gas	gaseous				X
7.5	Cyanic Water	aqueous				X
7.6	By-Product Naphtha	organic liquid			X	X
Tar/Oil Separation Section						
13.1	Tar Tank Vent	gaseous		X		
13.3	Medium Oil Tank Vent	gaseous		X		
13.6	Waste Gas to Flare	gaseous		X		
13.7	Phenolic Water Tank Vent	gaseous		X		
13.8	Heavy Tar	solid	X	X	X	
13.9	By-Product Light Tar	organic liquid			X	X
13.10	By-Product Medium Tar	organic liquid			X	X

(Continued)

TABLE 3-1. (Continued)

Sample Point	Stream Name	Media	Reason for Selection: High Discharge Rate	Reason for Selection: Significant Pollutant Concentration	Reason for Selection: Trace Pollutant Characterization	Reason for Selection: Informational Value
Phenosolvan Section						
14.5	Ammonia Stripper Vent	gaseous	X	X		
14.0	Phenosolvan Inlet Water	aqueous				X
14.11	Phenosolvan Wastewater	aqueous	X	X	X	
By-Product Storage Section						
15.3	Naphtha Storage Tank Vent	gaseous		X		
Flare System						
20.1	Combined Gas to Flare	gaseous	X	X	X	

3.2.3 Trace Pollutant Characterization

Some streams were selected to yield useful information as to the fate of the inorganic trace elements which enter the plant with the coal. In the gaseous phase, streams were selected before the water quenching step in the Gas Production section (low and high pressure coal lock vent gases) where trace elements could be discharged. Rectisol section gases were also chosen to determine the extent to which the more volatile trace elements could remain in the gas after the water quenching and cooling process. Aqueous, by-product and solid waste streams were selected to determine in which streams the various elements left the gasification system.

Trace organic characterization was considered to be an essential part of the Phase II test program. Analyses for trace organics were performed for all of the streams selected for other reasons. Particular emphasis was given to the trace organics in the Phenosolvan wastewater, heavy tar, and liquid by-products.

3.2.4 Informational Value

Some streams were included in the Phase II test plan because they would provide useful information for understanding the Kosovo plant operation or for determining the fate of important compounds. For example, the Phenosolvan inlet water was selected because it would allow the effectiveness of the Phenosolvan section to be studied. Similarly, the liquid by-products (light tar, medium oil, and naphtha) were included because many key compounds, including trace organics and inorganics, were likely to end up in these by-products In addition, the information obtained could aid in assessing the suitability of these by-products for use as on-site fuels.

3.3 SELECTION OF STREAM PROPERTIES FOR PHASE II TESTING

The stream properties selected for study in Phase II were included for one of three reasons: flow rate determination, stream composition characterization, or trace pollutant characterization. The sampling and analytical procedures used to develop these data are discussed in Section 4.

For gaseous streams, the dry gas mass flow rate was found by determining total stream volumetric flow rate, temperature, molecular weight, and moisture content. Gaseous stream compositions were determined by analyzing for fixed gases, hydrocarbons, sulfur species, and nitrogen species.

Aqueous stream quality was characterized by water quality parameters, such as COD and pH. Physical properties, dissolved and suspended solids, temperature, and trace pollutant concentrations were also determined.

For solid and organic liquid streams, Proximate, Ultimate, and trace pollutant analyses were performed. Resource Conservation and Recovery Act Extraction Procedure (RCRA EP) leachate analyses for trace elements in the gasifier ash were included to determine if a landfill was an acceptable disposal option for this stream. Information about the vapors from the by-product storage tanks was obtained by performing head space tests of the liquid by-product samples.

Bioassay tests were performed using samples from the following seven streams: dry gasifier ash, heavy tar, light tar, medium oil, naphtha, Phenosolvan inlet water, and Phenosolvan wastewater. These tests were performed to provide information about potential biological effects from the Kosovo plant's solid, liquid by-product, and wastewater streams.

SECTION 4

TEST METHODOLOGY

The data acquisition task of the Kosovo source test and evaluation program consisted of extensive sampling and analyses. The sampling and analytical methods employed in this program are described in this section. Accepted and publicly documented methods were used where practical. A brief summary of the sampling and analytical methods is given in Table 4-1.

4.1 SAMPLING METHODS

The descriptions of the sampling methods contained in this subsection are grouped by stream type (gas, liquid, solid) then within each stream type by analytical parameter. The majority of the sampling effort at Kosovo was directed toward gaseous streams. The sampling of these streams was more complex than the liquid or solid streams. The liquid and solid streams required a much smaller portion of the sampling effort.

4.1.1 Gas Streams

The descriptions of sampling methods in this program are centered on the apparatus used to collect the samples. The use of the sampling apparatus is assumed to be self-evident once the apparatus has been described. For the purpose of this discussion, the sampling apparatus or train used to collect samples for further characterization is divided into two parts, 1) that portion of the train to remove the gas to be characterized from the bulk of the gas stream (nozzle and probe) and 2) that portion of the train which collects those components of the gas stream to be actually analyzed (impingers, sorbents, etc.).

The configuration of the front half of the sampling train which extracts the gas from the stream is governed by the physical characteristics of the stream while the configuration of the back half of the sampling train is governed by the chemical species being collected for analysis.

The gas streams were grouped as presented in Table 4-2. The groupings were based on the probe-to-port sealing configuration required to gain access to the gas stream. Figure 4-1 shows the configuration of the sampling probe while the probe-to-port sealing mechanisms are shown in Figure 4-2 (A through D). Samples were obtained and the total flow rates of gases emitted from tank vents were measured with the apparatus shown schematically in Figure 4-3.

Even though the port, probe and sealing mechanism for most streams were similar, the sample collection devices (back half of the train) were varied to fit the collection requirements for each set of species to be analyzed. A description of the sampling equipment for each of the parameters listed in Table 4-1 follows.

TABLE 4-1. SAMPLING AND ANALYTICAL METHODS

Parameter	Collection Method	Analytical Method
CONDENSABLE HYDROCARBONS:		
Condensable Hydrocarbons	Gas stream cooled to 0°C and resulting condensate trapped in impingers. The remaining condensable hydrocarbons trapped on XAD-2 resin	Organic material extracted from condensate and resin with CH_2Cl_2 Extract analyzed with gas chromatograph and gas chromatography/mass spectrometry
Benzene, Toluene, and Xylene	Vapors trapped from gas stream by activated carbon	Vapors solvent extracted from carbon and analyzed by GC with flame ionization detector
GASEOUS SPECIES BY GC:		
Fixed Gases (CO, H_2, CO_2, N_2, O_2, CH_4)	Sample was heated, filtered and dried then compressed into silanized glass bombs for analyses	Gas chromatograph with thermal conductivity detector
Hydrocarbons C_1-C_6, C_6+ Benzene, Toluene and Xyelene	Sample was heated, filtered and dried then compressed into silanized glass bombs for analyses	Gas chromatograph with flame ionization detector
Sulfur Species (H_2S, COS, CS_2, SO_2, Mercaptans)	Sample was heated, filtered and dried then compressed into silanized glass bombs for analyses	Gas chromatograph with flame photometric detector

(Continued)

TABLE 4-1. (CONTINUED)

Parameter	Collection Method	Analytical Method
PARTICULATE:		
Suspended Particulate	EPA Method 5, gas filtered at 250°F out of stack	Gravimetric
	EPA Method 17, gas filtered at duct temperature in stack	Gravimetric
Suspended Particulate Plus Condensables	Condensation and collection in a series of water filled impingers	Filtration, extraction with CH_2Cl_2, Gravimetric
TRACE ELEMENTS:		
Non-Volatile Elements (Be, Cd, Co, Cr, Cu, Mo, Ni, Pb, Sr, Te, V, Zn)	2 impingers with 10% HNO_3 followed by 2 impingers with 10% NaOH	Dissolution, AA with graphite furnace
Volatile Elements (Hg, As, Sb, Se)	2 impingers with 10% HNO_3 followed by 2 impingers with 10% NaOH	Dissolution, AA with Hydride Generation
Iron and Nickel Carbonyls	2 fritted impingers with 3% HCl	AA with Graphite Furnace

(Continued)

TABLE 4-1. (Continued)

Parameter	Collection Method	Analytical Method
OTHER GASES:		
Ammonia	2 fritted impingers with 0.1 N H_2SO_4	Distillation into boric acid and back titration with sulfuric acid
Hydrogen Sulfide	2 fritted impingers with 0.1 N cadmium acetate	Iodine addition and back titration with thiosulfate
Hydrogen Cyanide	2 fritted impingers with 0.1 N cadmium acetate followed by 2 fritted impingers with 0.1 N NaOH	Distillation and titration with silver nitrate
Phenols	2 fritted impingers with 0.1 N NaOH	Spectrophotometric determination by reaction with 4-aminoantipyrine

TABLE 4-2. PROBE/PORT CONFIGURATION FOR KOSOVO GAS STREAMS

Stream Characteristics	Probe/Port Configuration
A. Atmospheric pressure, non-toxic components	Probe sealed at port with fabric stuffing
B. Moderate pressure and/or toxic components	Probe sealed at port with packing gland
C. Moderate pressure and/or highly toxic components	Probe sealed at port with packing gland and isolated from gas stream with a gate valve
D. High pressure	Probe sealed at port with packing gland and isolated from gas stream with a gate valve. Mechanical drive used to insert probe against stream pressure
E. Tank vents to atmosphere	Total stream routed through a calibrated orifice - sample obtained through Teflon® tube

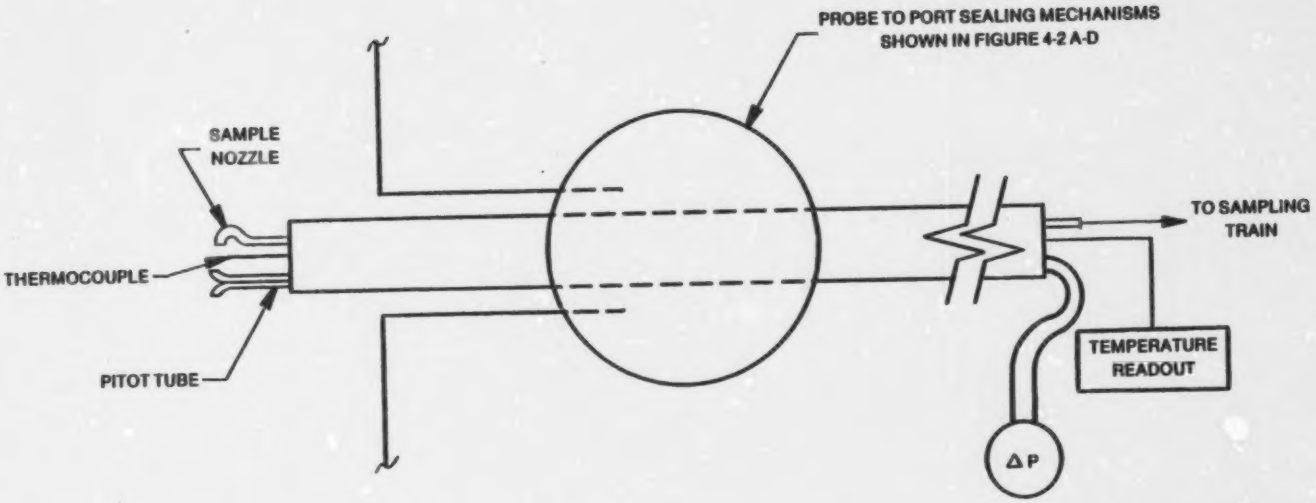
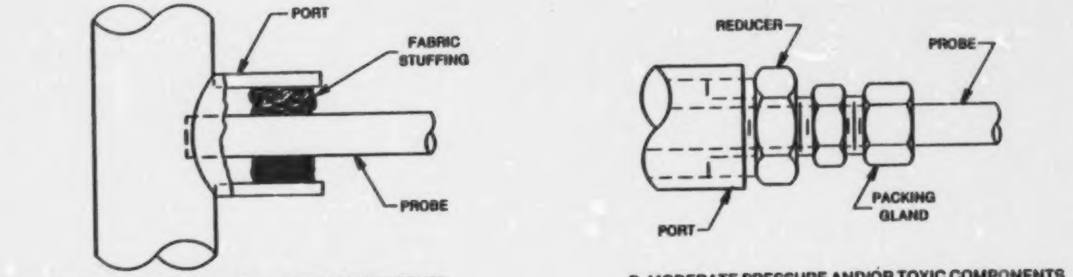
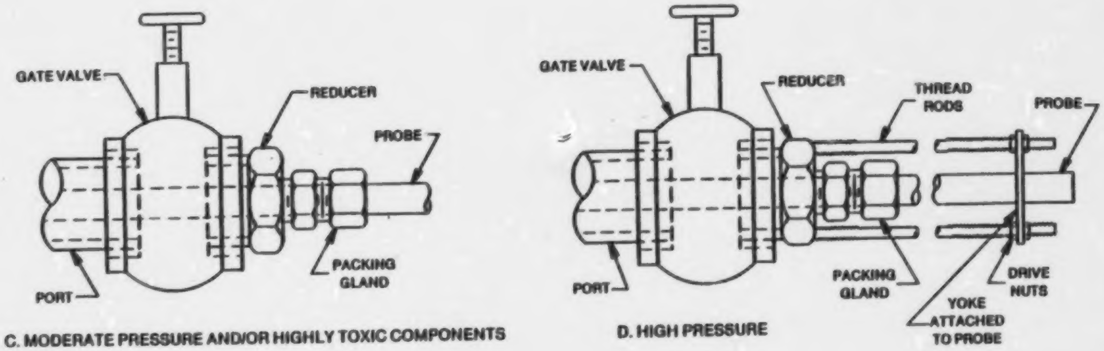

PROBE TO PORT SEALING MECHANISMS
SHOWN IN FIGURE 4-2 A-D
SAMPLE
NOZZLE
THERMOCOUPLE
PITOT TUBE
TO SAMPLING
TRAIN
TEMPERATURE
READOUT
ΔP

Figure 4-1. Probe configurations.


PORT
FABRIC STUFFING
PROBE
REDUCER
PROBE
PORT
PACKING GLAND

A. ATMOSPHERIC PRESSURE, NON-TOXIC COMPONENTS

B. MODERATE PRESSURE AND/OR TOXIC COMPONENTS


GATE VALVE
REDUCER
PROBE
PORT
PACKING GLAND
GATE VALVE
REDUCER
THREAD RODS
PROBE
PORT
PACKING GLAND
DRIVE NUTS
YOKE ATTACHED TO PROBE

C. MODERATE PRESSURE AND/OR HIGHLY TOXIC COMPONENTS

D. HIGH PRESSURE

Figure 4-2.. Probe to port sealing mechanism.

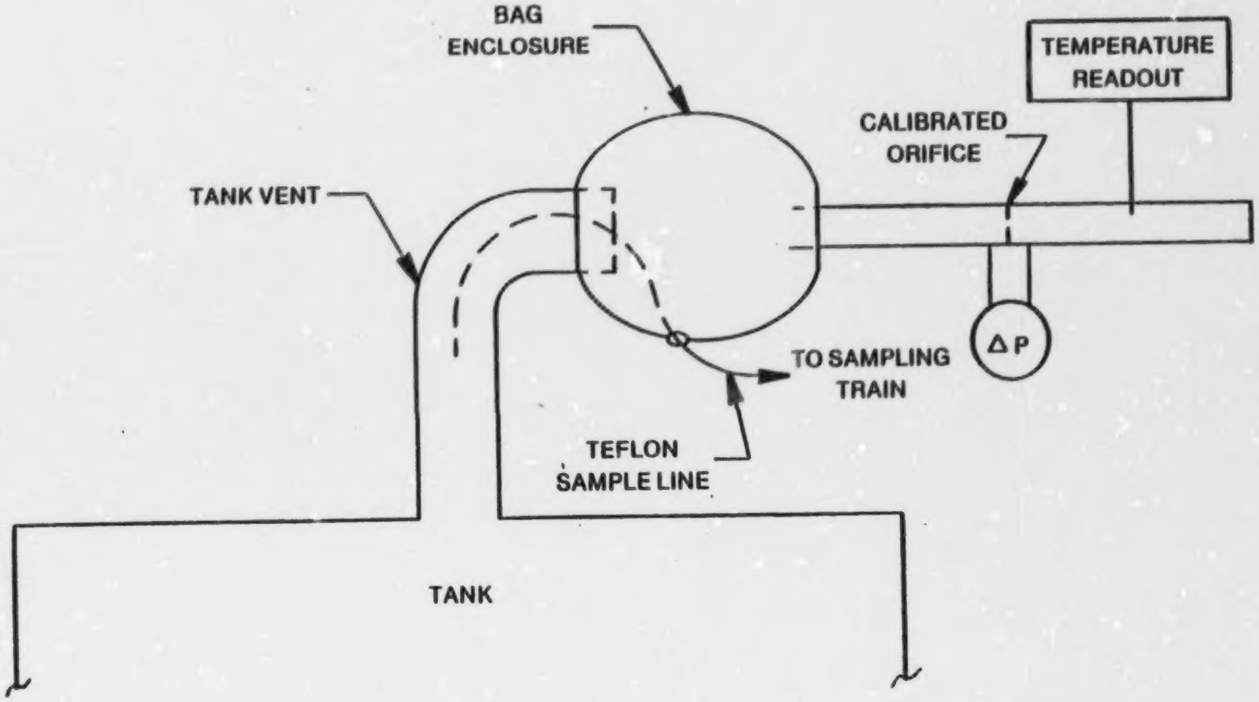

BAG
ENCLOSURE
TEMPERATURE
READOUT
CALIBRATED
ORIFICE
TANK VENT
ΔP
TO SAMPLING
TRAIN
TEFLON
SAMPLE LINE
TANK

Figure 4-3. Sampling apparatus for tank vent.

4.1.2 Mass Flow Rate

The flow rates of the gas streams sampled were determined from the data collected during sampling. These data included the pressure differential generated by the pitot attached to the probe and the gas density. The gas density was calculated from the gas composition, gas temperature, and gas stream pressure. The S-type pitot and thermocouple are shown in Figure 4-1.

A description of the methods used to determine the gas flow rate for each stream is contained in EPA Reference Methods 1 through 4 (Ref. 4-1).

An alternate procedure was used to obtain samples and measure flow for tank vents discharged directly to the atmosphere. Gas from these small vents was routed through a calibrated orifice as shown in Figure 4-3. The gas flow rate was calculated from the pressure drop across the orifice and the gas density. Samples for collection and analysis were extracted through a flexible Teflon® tube inserted upstream of the orifice.

4.1.3 Condensable Hydrocarbons

Two collection techniques were used to obtain samples for analysis of condensible hydrocarbons. The less volatile species were collected by condensation following by sorption of any remaining vapor with a porous polymer resin (XAD-2®). The more volatile species were sorbed by activated carbon using a different train. In terms of collecting ability, the division between these two techniques is not sharp. The samples from the XAD-2® collection technique were analyzed for hydrocarbons having boiling points above that of naphthalene while the charcoal tubes were analyzed for benzene, toluene, and xylene.

The higher boiling condensable hydrocarbons were collected by a train, as shown in Figure 4-4, consisting of impingers as follows:

1st and 2nd - 0.2L distilled water
3rd - 100 g of clean prepared XAD-2® resin
4th - preweighed silica gel

The impingers were placed in an ice bath during sampling. Gas streams with a high moisture content, above 50% by volume, were sampled with empty impingers placed upstream of those shown in Figure 4-2 to remove the excess condensate and provide additional cooling of the gas sampled.

Remaining hydrocarbons were sorbed by the resin held in a canister made from a modified impinger. Coarse glass frits were used at the entrance and exit of the canister to prevent the loss of resin. Pre-weighed silical gel in the last impinger trapped any remaining water vapor.

Sampling was prformed isokinetically with flow rates of approximately 1.4 E-04 Nm^3/s. Typical sampling volumes were 0.2 to 0.5 Nm^3.

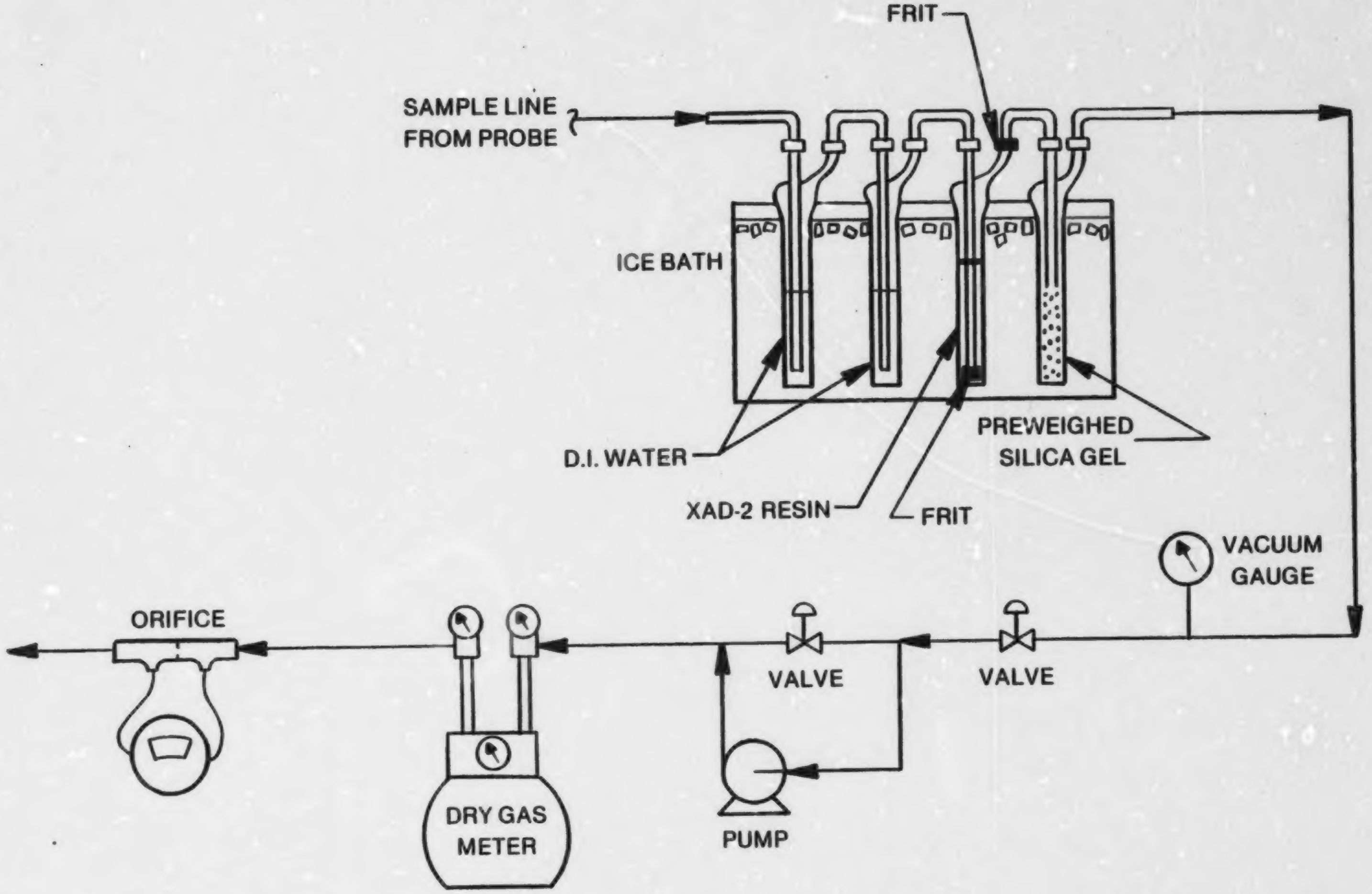

FRIT
SAMPLE LINE
FROM PROBE
ICE BATH
PREWEIGHED
SILICA GEL
D.I. WATER
XAD-2 RESIN
FRIT
VACUUM
GAUGE
ORIFICE
VALVE
VALVE
DRY GAS
METER
PUMP

Figure 4-4. Condensable organic sampling train.

Material for analysis was recovered from the impingers as well as the nozzle, probe liner, and interconnecting tubing and glassware. Material was recovered from the probe and sample line with a methylene chloride rinse. The aqueous portion of the impinger solutions was separated and stored. Remaining organic material from the impingers and connecting glassware was recovered with a methylene chloride rinse which was then combined with the probe rinse. The XAD-2® resin and any sorbed hydrocarbons were transferred to the original resin container. The silica gel was reweighed to determine its weight increase due to moisture collection, then discarded.

A second technique was used to collect light aromatics (benzene, toluene and xylene) which were poorly retained by the XAD-2® resin. The activated charcoal collection tubes used for this technique had a four cubic centimeter primary collection zone and a one cubic centimeter secondary collection zone. A large gas tight syringe was used to draw samples through the collection tubes at 5 E-06 to 8 E-07 Nm^3/s. Typically, multiple tubes were collected with the sample volume spanning at least an order of magnitude. The actual volumes were based on the suspected light hydrocarbon content of the stream and ranged from 1 E-05 to 2 E-03 Nm^3. After the samples were drawn through the tubes, the sampling time, location, and volume were recorded, the tube ends were capped, and the tubes were stored in a refrigerator until analysis.

4.1.4 Gases for Gas Chromatographic Analysis

Samples for gas chromatographic (GC) analysis were collected with the apparatus shown in Figure 4-5. These samples were analyzed for fixed gases (N_2, O_2, H_2, CO, CO_2 and CH_4), hydrocarbons, and sulfur species. The purpose of the sampling and conditioning system was to remove particulates and lower the dewpoint of the gas prior to cooling and pressurization into pretreated bombs. Particulates were trapped on a silanized glass fiber filter and the moisture removed by a PermaPure® dryer. The gas was then cooled and pumped into silonized glass bombs. The 0.5L bombs were purged with 5.0L of conditioned sample and then pressurized to 50 kPa (0.5 atm). Immediately after collection, each sample was transferred to the laboratory for analysis.

A fixed gas analysis was performed on each sample to assure that it had not been contaminated with air prior to performing the more time consuming hydrocarbon and sulfur species analyses.

4.1.5 Particulates

The particulate concentration of the gas streams was determined by one of two techniques. In both techniques, the particulate mass collected was determined gravimetrically. For gas streams with lower levels of condensables (oils, tars and moisture) the particulate material was collected on a heated filter. For gas streams with higher levels of condensables, the particulates were collected in a series of water-filled impingers. The oils and tars were extracted from the resulting impinger solutions by extraction with methylene chloride. Particulate matter remaining in the impinger solutions or in the oils and tars extract was then removed by filtration.

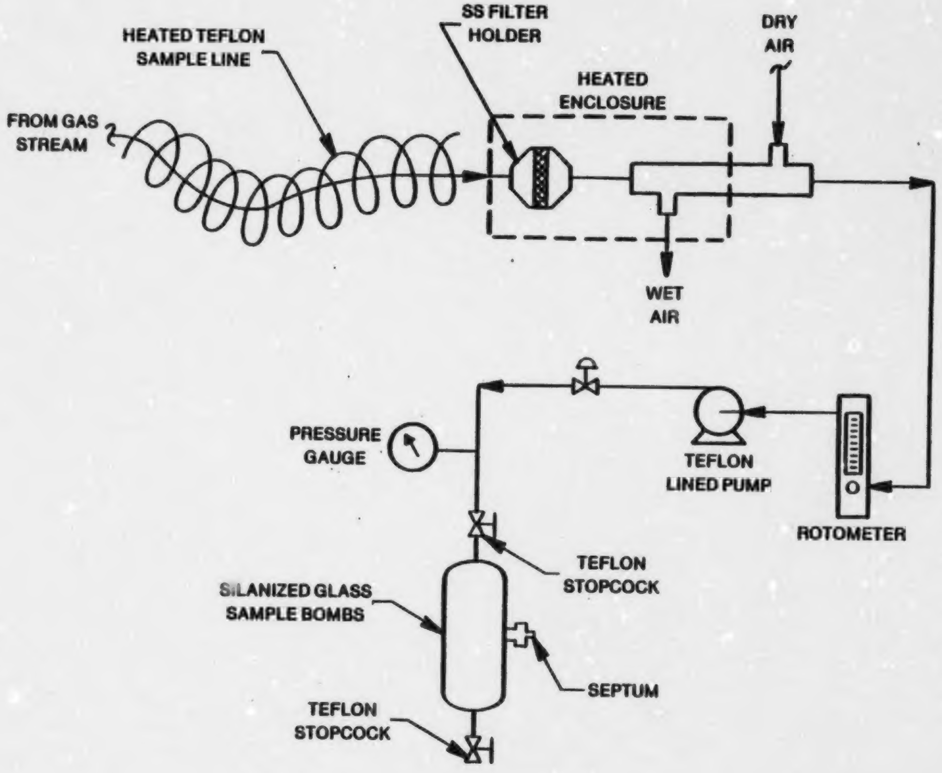

HEATED TEFLON
SAMPLE LINE
SS FILTER
HOLDER
DRY
AIR
HEATED
ENCLOSURE
FROM GAS
STREAM
WET
AIR
PRESSURE
GAUGE
TEFLON
LINED PUMP
ROTOMETER
TEFLON
STOPCOCK
SILANIZED GLASS
SAMPLE BOMBS
SEPTUM
TEFLON
STOPCOCK

Figure 4-5. Gas sampling and conditioning apparatus.

EPA Reference Method 5 (Ref. 4-1) was used to determine particulate concentrations in streams with low levels of condensables. Gas was drawn isokinetically from the duct through a stainless steel button-hook nozzle and a heated stainless steel lined probe. Particulates were then removed by a glass fiber filter held at 121°C (250°F). The gas exiting the filter was passed through a series of four impingers for the removal of condensables and water vapor. Material was recovered from the probe, nozzle, and all connection glassware prior to the filter using an acetone rinse aided with a brush. The filter, with any particulates, was transferred to a clean tared petri dish.

The second technique used a series of water filled impingers for particulate collection. The train had the same features and was used in the same manner as the Method 5 train described in the previous paragraph, however, the filter was bypassed. This technique allowed the collection of the large mass of condensables without the filter blockage which would have occurred with a Method 5 train.

The sample was recovered from the probe nozzle and lined with a methylene chloride rinse. The weight increase of the impinger solution was determined before the aqueous phase was transferred to storage containers. Then the impingers and all interconnecting glassware were rinsed with methylene chloride to recover condensed oils and tars. This rinse was combined with the probe and nozzle wash.

The impinger collection technique for particulates was combined with the condensable hydrocarbon train (Section 4.1.3) when values for both parameters were desired. Aliquots from each sample fraction prior to the XAD-2® resin catch were taken for particulate determinations.

The weight increase of the impingers was recorded and the probe and nozzle rinse (or aliquots) and impinger solution (or aliquots) were stored for analysis of filterable particulates, condensable oils and tars recovered by extraction, and dissolved solids recovered from the aqueous phase.

4.1.6 Trace Elements

Trace elements were collected in a series of seven impingers with contents as follows:

Impingers	Content
1 & 2	0.2L 10% HNO^3
3	empty
4 & 5	0.2L 10% KOH
6	empty
7	preweighed silica gel

Gas was drawn through a nozzle, probe, and sample line and then the series of impingers listed above. As much sample as practical was collected to increase sensitivity. The limiting factor on sample volume was the accumulation of condensable oils and tars or the formation of excessive carbonate precipitate in the KOH impingers. Typical isokinetic flow rates were 9.4 E-05 to 1.6 E-04 Nm^3/s. A recovered sample consisted of four impinger solutions with connecting glassware being rinsed into the previous impinger with distilled water, plus a methylene chloride rinse of the nozzle, probe, sample line, and all empty glassware.

Samples for analysis of metal carbonyls were collected with a train consisting of two impingers each containing 0.5L of 3% HCl. Typical flow rates were 3 E-05 Nm^3/s with sample volumes of 0.2 to 0.3 Nm^3. The gas stream was filtered before entering the impinger and was assumed to be in the volatile carbonyl form. The recovered impinger solutions and glassware rinses were stored separately for analysis.

4.1.7 Ammonia, Hydrogen Sulfide, Hydrogen Cyanide, and Total Phenols

Ammonia, hydrogen sulfide, hydrogen cyanide and total phenols were collected independently from the gas stream using fritted impingers in series. The impinger solutions for each run were as follows:

	No. of Impingers	Solution
Ammonia	2	0.05L 0.1N H_2SO_4
Hydrogen sulfide	2	0.05L 4% Cadmium acetate
Hydrogen cyanide	2	0.05L Cadmium acetate
	2	10% NaOH
Phenols	2	0.05L 5% NaOH

4.1.8 Liquid Samples

Liquid samples were collected either with a dipper from streams with an open hatchway, or from a spigot. The entrainment of air was avoided where possible. Sample bottles were filled completely to minimize head space. Sample containers and preservatives appropriate for each of the planned analytical techniques were used.

4.1.9 Solid Samples

Most solid samples were collected at the outfall of a conveyor and stored in appropriate containers. Grab samples of the dry bottom ash were collected from the transfer line connecting the lower ash lock valve with the ash quench chambers. Heavy tar was collected as a liquid and allowed to cool and solidify.

4.2 ANALYTICAL METHODS

The analytical methods used during the Kosovo tests are described in this subsection. Where applicable, methods accepted and/or documented by recognized organizations were used. These organizations include the U.S. Environmental Protection Agency, American Society for Testing and Materials (ASTM), German Institute for Standardization (DIN) and the Soviet State Committee on Standards (GOST).

The analytical procedures discussed in this section address the following sample types:

- gases,
- aqueous liquids,
- solids, and
- by-products.

Most of the analytical techniques used vary little for the different sample types after the initial sample preparation has been performed. The descriptions in this section are thus grouped by method. The preparation required for each sample type, if required, is described as part of the method.

4.2.1 On-Site Gas Analysis

Gas chromatographic (GC) techniques were used to analyze fixed gases, hydrocarbons and vapor phase sulfur species in gas samples collected and contained in pressurized glass bombs. The fixed gases were analyzed prior to the other gases, thus verifying the sample integrity prior to starting the more detailed and time consuming gas analyses. A flow scheme for these analyses is shown in Figure 4-6. Table 4-3 describes the instrument, column, temperature program, and detector used for each analysis.

4.2.2 Preparation of Samples for Organic Analysis

The scheme presented in this section addresses the preparation of samples collected as described in Sections 4.1.3 (condensable hydrocarbons), 4.1.8 (liquids), and 4.1.9 (solids). Once prepared or extracted, the analysis of each sample type was the same. The types of samples prepared for organic analysis were:

- condensable organics sorbed on XAD-2® resin,
- methylene chloride sample train rinses,
- aqueous liquids,
- by-products, and
- solids.

A sample may have extracts from two or more of the above classifications. If so, these extracts were prepared individually then composited to form a single sample for organic analysis. The numerical fraction of each extract composited was the same for all extracts of a given sample. The extraction and preparation procedures for each type of sample or matrix are discussed in this subsection (4.2.2). Descriptions of the analyses of the composited extracts follows in subsection 4.2.3.

XAD-2® Resin

A porous polymer resin (XAD-2®) was used to sorb vapor phase organics from the sample stream. Prior to sampling the resin was cleaned to reduce

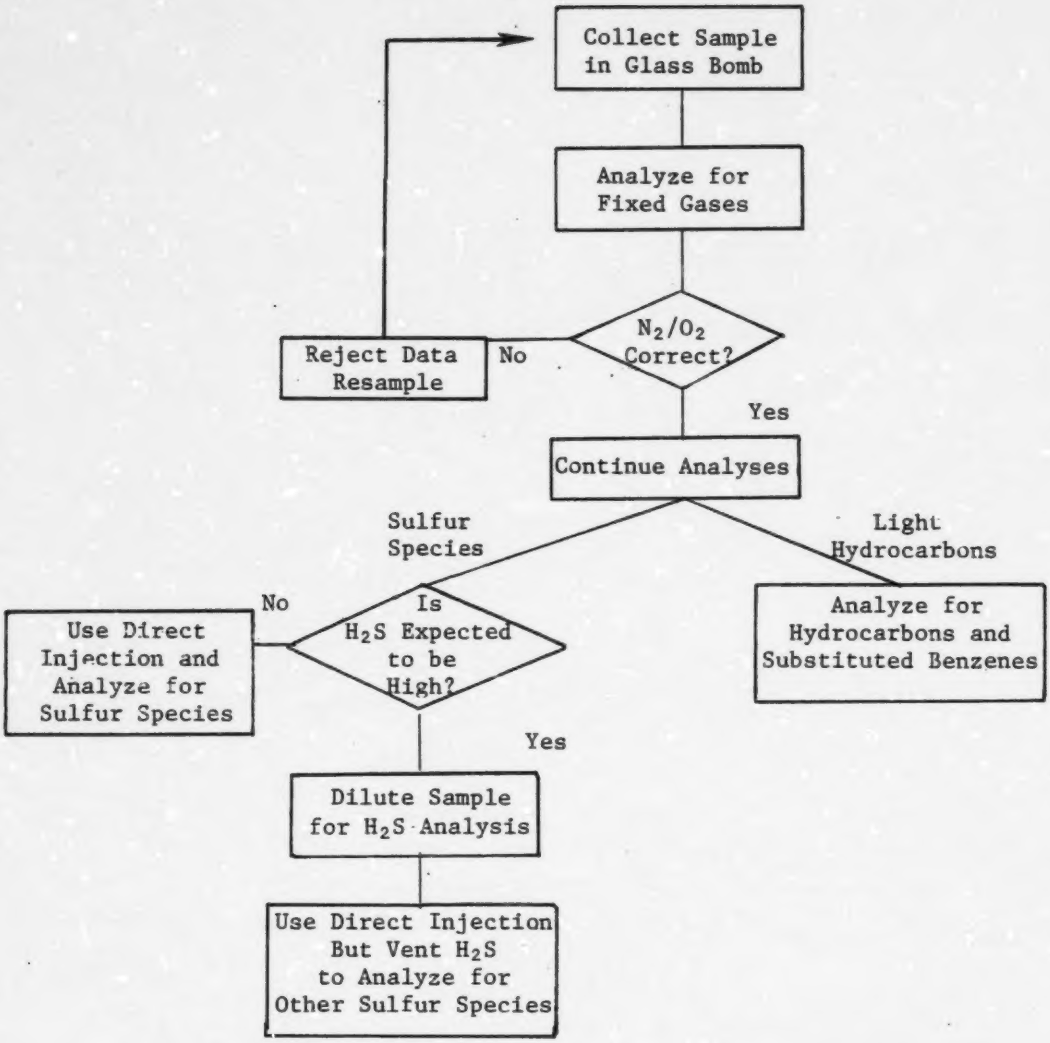

Collect Sample in Glass Bomb
Analyze for Fixed Gases
N_2/O_2 Correct?
No
Reject Data Resample
Yes
Continue Analyses
Sulfur Species
Light Hydrocarbons
Analyze for Hydrocarbons and Substituted Benzenes
Is H_2S Expected to be High?
No
Use Direct Injection and Analyze for Sulfur Species
Yes
Dilute Sample for H_2S Analysis
Use Direct Injection But Vent H_2S to Analyze for Other Sulfur Species

Figure 4-6. Flow scheme for on-site gas chromatographic analyses.

TABLE 4-3. ON-SITE GAS CHROMATOGRAPHIC ANALYSIS - INSTRUMENTS AND CONDITIONS

Sulfur Species (H_2S, CS_2, COS, SO_2, CH_3SH, CH_3CH_2SH)	Hewlett-Packard Model 5730A with FPD*	3m x 1/8" O.D. Teflon® packed with 1% TCEP 0.5% H_3PO_4 on 80-100 mesh Carbopak B	Hold 4 min @ 40°C, 16°C/min to 110°C, hold 12 min @ 110°C
Fixed Gases (O_2, N_2, H_2, CO_2, CO, CH_4)	Varian Aerograph Model 90-P with TCD*	3m x ¼" O.D. Glass packed with 60-80 mesh, 13x molecular sieve	Isothermal @ 50°C
Benzene, Toluene, Xylenes	Varian Aerograph Model 1400 with FID*	3m x ¼" O.D. S.S. packed with 10% Carbowax 20 m on 80-100 mesh Chromosorb W AW	Isothermal @ 120°C
Hydrocarbons (C_1-C_6, C_6+) and Fixed gases (CO_2, CO, CH_4, H_2, O_2, N_2)	Hewlett-Packard Model 5840A with TCD & FID*	1) 9m x 1/8" O.D. S.S. packed with 16% Bis-2-(methoxyethyl) adipate on 80-100 mesh Chromosorb P AW, 2m packed with 30% DC-200 on 80-100 mesh Chromosorb P AW 2) 3m x 1/8" O.D. S.S. packed with 60-80 mesh 13X molecular sieve 3) 2m x 1/8" O.D. S.S. packed with 60-80 mesh Poropak Q	Isothermal @ 50°C

*FID = Flame Ionization Detector
TCD = Thermal Conductivity Detector
FPD = Flame Photometric Detector

background interferences which would be extracted during sample recovery. The cleaning process for the resin consisted of a water wash to eliminate fines followed by a methanol (CH_3OH) wash. The resin was then soxhlet extracted for 24 hours with CH_3OH, then pyridine, and finally diethyl ether. After cleaning, the resin was stored under CH_3OH. Just prior to use it was thoroughly drained and rinsed with clean water. Blanks were used to correct for any organic material which was extracted from the clean resin during sample recovery. The organics sorbed (or condensed) during sampling were recovered from the resin by extraction with methylene chloride (CH_2Cl_2). The extracted organics were then separated into two fractions, one containing the acids and the other containing the base/neutrals. The extracts were separated into these fractions by liquid partitioning between the CH_2Cl_2 solvent and water (ph adjusted to 12 with NaOH for the base/neutrals). The aqueous layer containing the acids was then back extracted with CH_2Cl_2 after adjusting the pH to 1 with HCl. The resulting acid and base/neutral fractions were then combined with other like fractions from other portions of the same sample if appropriate. The extraction flow scheme for the resin is shown in Figure 4-7.

Sample Train Rinses

Sample recovery from a gas sample collection included a rinse of the sampling train with CH_2Cl_2. This rinse removed organics and particulates coating the interior walls of the train. The scheme, shown in Figure 4-8, recovered the material for preparation and eventual combination with the extracts of the same sample. Acid and base/neutral fractions were separated by back extraction as done for the resin.

Particulates contained in the rinse were quantified by gravimetrically determining the residue after filtration. Condensable tars and oils were quantified by determining the residue after evaporation. These results were combined with the filterable and dissolved solids from the aqueous portion of the impinger solutions to determine the total particulate catch.

Aqueous Liquids

The aqueous and non-aqueous phases of liquid samples were separated if present. The aqueous phase was then extracted with CH_2Cl_2, first at a pH of 12 then at a pH of 1. This scheme is shown in Figure 4-9. The resulting base/neutral and acid fractions were carried on to subsequent portions of the analytical scheme or, if the aqueous liquid was a portion of a sample, they were combined with other like fractions for subsequent analyses.

If the aqueous liquid was an impinger solution from a particulate sample, the aqueous phase was reserved and the dissolved solid content was determined for inclusion in the particulate value.

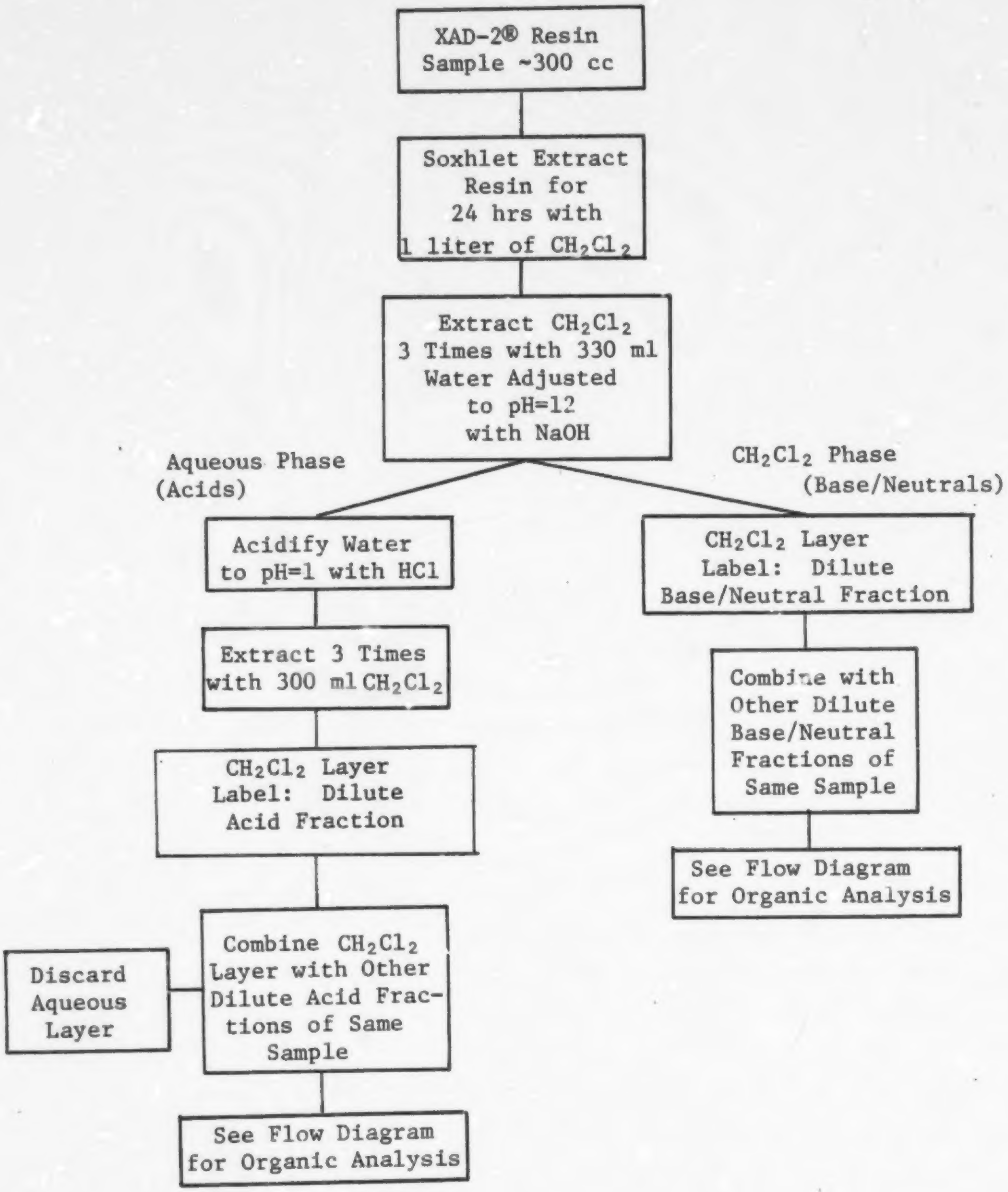

XAD-2® Resin Sample ~300 cc
Soxhlet Extract Resin for 24 hrs with 1 liter of CH_2Cl_2
Extract CH_2Cl_2 3 Times with 330 ml Water Adjusted to pH=12 with NaOH
Aqueous Phase (Acids)
CH_2Cl_2 Phase (Base/Neutrals)
Acidify Water to pH=1 with HCl
Extract 3 Times with 300 ml CH_2Cl_2
CH_2Cl_2 Layer Label: Dilute Acid Fraction
Discard Aqueous Layer
Combine CH_2Cl_2 Layer with Other Dilute Acid Fractions of Same Sample
See Flow Diagram for Organic Analysis
CH_2Cl_2 Layer Label: Dilute Base/Neutral Fraction
Combine with Other Dilute Base/Neutral Fractions of Same Sample
See Flow Diagram for Organic Analysis

Figure 4-7. XAD-2® resin extraction flow scheme.

ANALYSIS OF RINSES

Special Case: Measurement of Particulates and Condensables in the Probe and Filter

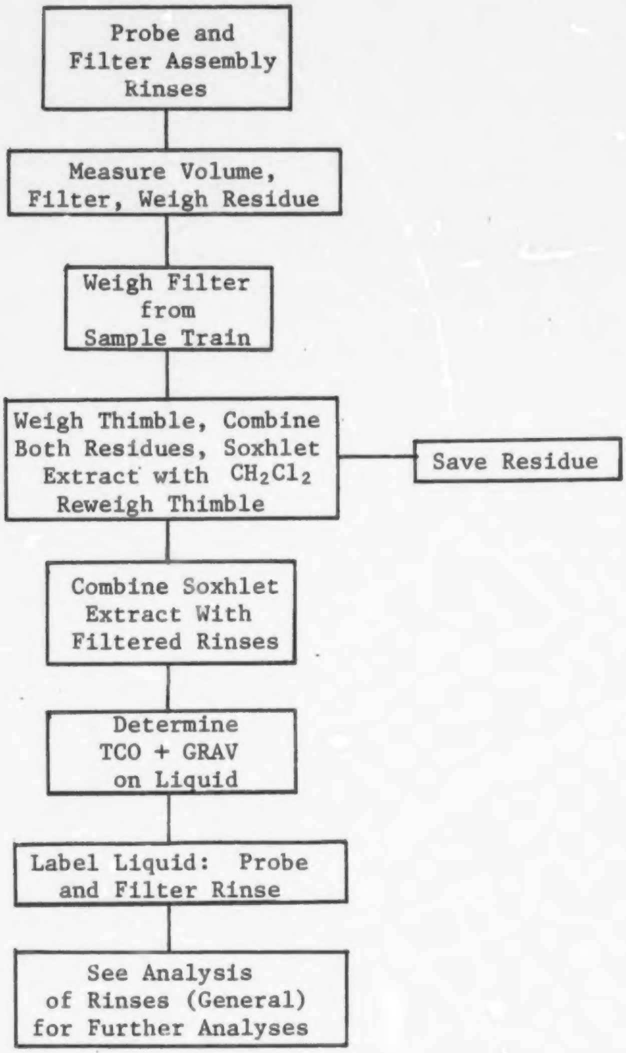

Probe and Filter Assembly Rinses
Measure Volume, Filter, Weigh Residue
Weigh Filter from Sample Train
Weigh Thimble, Combine Both Residues, Soxhlet Extract with CH_2Cl_2 Reweigh Thimble
Save Residue
Combine Soxhlet Extract With Filtered Rinses
Determine TCO + GRAV on Liquid
Label Liquid: Probe and Filter Rinse
See Analysis of Rinses (General) for Further Analyses

Figure 4-8. Flow scheme for the preparation of sample train rinses.

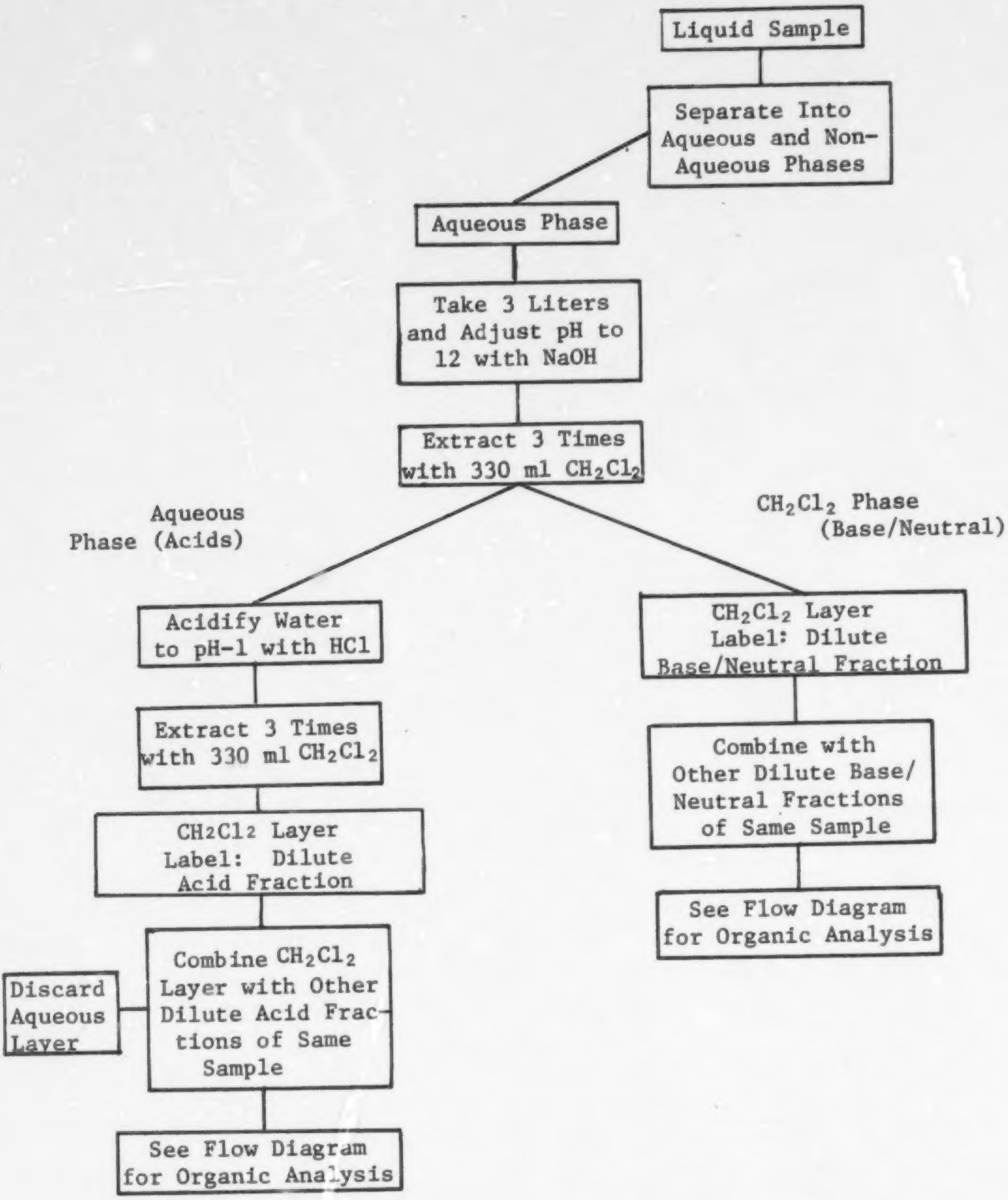

Liquid Sample
Separate Into Aqueous and Non-Aqueous Phases
Aqueous Phase
Take 3 Liters and Adjust pH to 12 with NaOH
Extract 3 Times with 330 ml CH_2Cl_2
Aqueous Phase (Acids)
CH_2Cl_2 Phase (Base/Neutral)
Acidify Water to pH-1 with HCl
Extract 3 Times with 330 ml CH_2Cl_2
CH_2Cl_2 Layer Label: Dilute Acid Fraction
Discard Aqueous Layer
Combine CH_2Cl_2 Layer with Other Dilute Acid Fractions of Same Sample
See Flow Diagram for Organic Analysis
CH_2Cl_2 Layer Label: Dilute Base/Neutral Fraction
Combine with Other Dilute Base/Neutral Fractions of Same Sample
See Flow Diagram for Organic Analysis

Figure 4-9. Flow scheme for the extraction of aqueous liquid samples.

Solids

A known weight of solid sample was transferred to a soxhlet thimble, weighed, and extracted with CH_2Cl_2 for 24 hours. The extract was then back extracted to generate base/neutral and acid fractions as was done for the XAD-2® scheme. Solids remaining after extraction were reweighed to determine the percent extractables present in the sample. This preparation scheme is the same as shown in Figure 4-7.

By-Products

The by-products from the Kosovo plant were diluted with a known volume of CH_2Cl_2 and then filtered to remove particulates and insoluble matter. The CH_2Cl_2 was then back extracted to generate the base/neutral and acid fractions for introduction into the remainder of the analytical scheme. This preparation scheme is shown in Figure 4-10.

4.2.3 Organic Analysis

Following the extraction step, aliquots of each fraction of a given sample were combined to form a composite sample for analysis and reserved. The remaining portions of these base/neutral and acid fractions were concentrated separately using Kuderna-Danish concentrations equipped with 3-stage Snyder columns. Aliquots of these concentrates were set aside for gas chromatography/mass spectrometry (GC/MS) analysis and remaining portions were combined and reserved.

PNA Analysis

Concentrated extracts which were prepared as described in Section 4.2.2 were analyzed for several selected polynuclear aromatics (PNA) by GC/MS.

The compounds analyzed were:

- Benz(a)anthracene
- 7,12-Dimethylbenz(a)anthracene
- Benzo(a)pyrene
- Benzo(a)fluoranthene
- 3-Methylcholanthrene
- Dibenz(a,h)anthracene
- 252 molecular weight group (as Benzo(a)pyrene)

A Hewlett-Packard 5982A GC/MS equipped with a liquid crystal column was used for these analyses. The liquid crystal N,N'bis(p-phenylbenzylidene), 2-2'-bi-p-toluidine (BPhBT) gave the required separation of these compounds including the 252 molecular weight isomers listed.

The selected ion monitoring (SIM) technique was employed for all analyses. The intensities of key ions were monitored during the chromatographic separation. Identifications of the selected compounds were based on the appearance of these key ions at previously established retention times. A

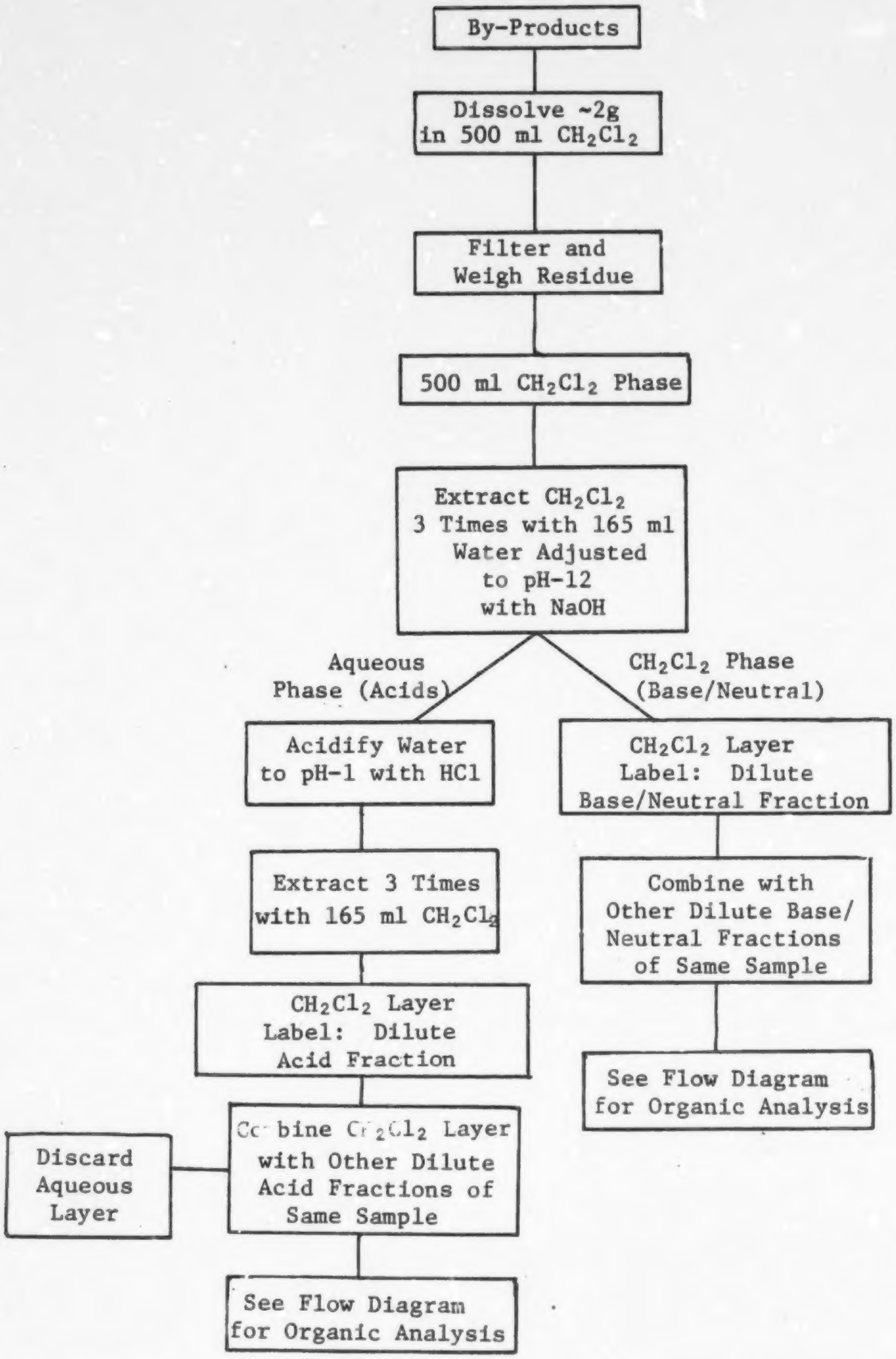

By-Products
Dissolve ~2g in 500 ml CH2Cl2
Filter and Weigh Residue
500 ml CH2Cl2 Phase
Extract CH2Cl2 3 Times with 165 ml Water Adjusted to pH-12 with NaOH
Aqueous Phase (Acids)
CH2Cl2 Phase (Base/Neutral)
Acidify Water to pH-1 with HCl
CH2Cl2 Layer Label: Dilute Base/Neutral Fraction
Extract 3 Times with 165 ml CH2Cl2
Combine with Other Dilute Base/ Neutral Fractions of Same Sample
CH2Cl2 Layer Label: Dilute Acid Fraction
See Flow Diagram for Organic Analysis
Discard Aqueous Layer
Combine CH2Cl2 Layer with Other Dilute Acid Fractions of Same Sample
See Flow Diagram for Organic Analysis

Figure 4-10. Flow scheme for the preparation of by-products.

second criterion for identification was the relative intensity of the secondary ion of each compound matching within 20% of the intensity found from the analysis of a standard. The quantification of these compounds was achieved by examination of the areas under the intensity profiles of a key ion for each compound. These were compared to the mass and area under the intensity profile of a series of at least four standards at varying concentrations.

All analyses were performed in duplicate. Positive identification and quantitation of 7,12-dimethylbenz(a)anthracene and 3-methylcholanthrene were not possible since standards of these compounds and their isomers were not available.

Head Space Analysis

Samples of the vapors present in the headspace above by-products (not extracts) were analyzed for light hydrocarbons, and sulfur species. The analytical techniques were described in Section 4.2.1, On-Site Gas Analysis. A flow scheme for these analyses is shown in Figure 4-11.

Charcoal Tubes

Light aromatic hydrocarbons which had been collected by sorption on charcoal tubes were extracted into carbon disulfide. The aromatics present in the extract were analyzed using a GC with a flame ionization detector. A 2m x 1/8" O.D. glass column packed with 10% carbowax 20M on Chromosorb W AW was used in the instrument. The column oven was maintained at 120°C during the analysis.

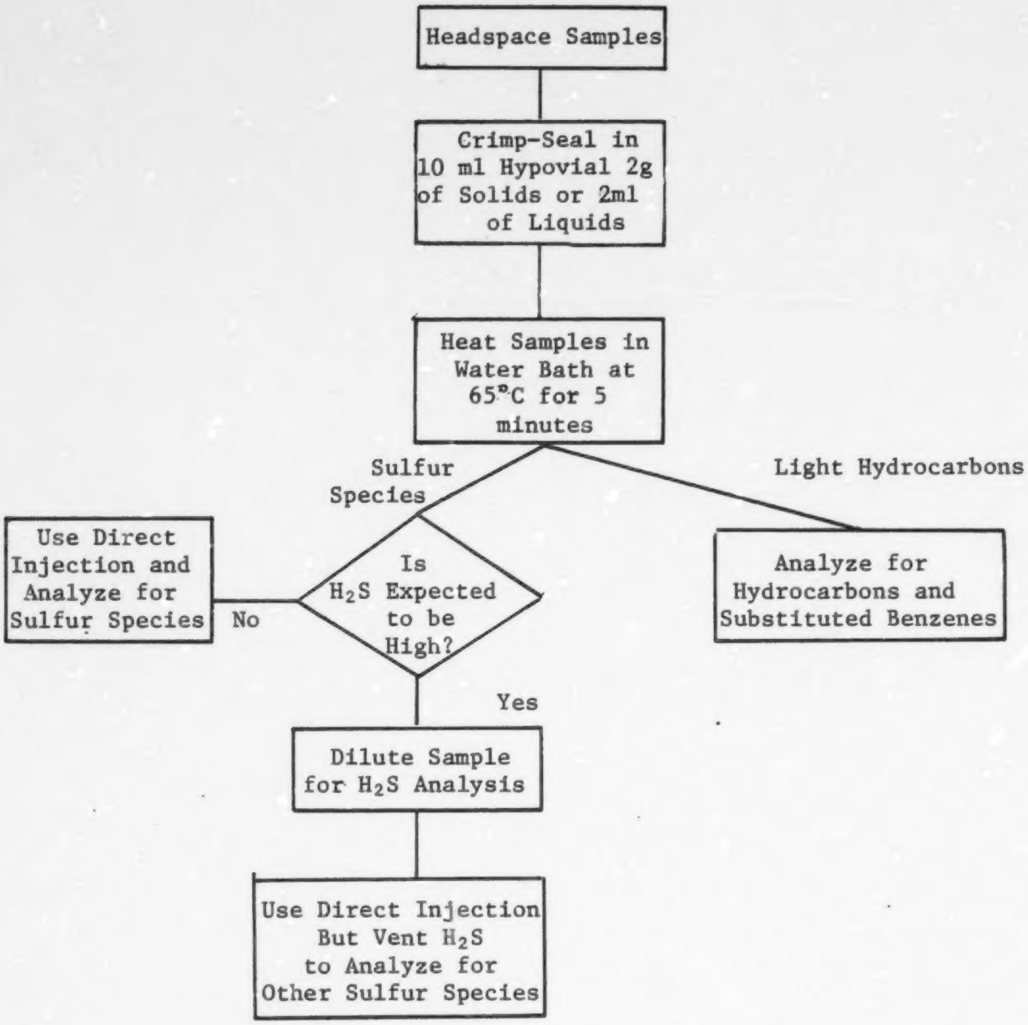
4.2.4 Trace Elements

Samples from gas streams obtained for trace element analysis were recovered in several fractions. These fractions were:

- probe, nozzle, and sample line wash with CH_2Cl_2,
- filtered solids or filter catch, and
- four impinger solutions,
  - 2 10% HNO_3 (0.2L)
  - 2 10% KOH (0.2L)

Sample fractions collected for metal carbonyl analysis consisted of two impinger solutions of 3% HCl, each approximately 0.5 liters in volume. The CH_2Cl_2 solutions were divided into two equal fractions. One fraction was analyzed for its particulate content as described previously, the other was analyzed for its trace element content. The fraction for trace element analysis was evaporated to dryness, then treated with HNO_3, H_2O_2, and HF as required to digest the sample. The resulting solutions were diluted to a known volume.

The impinger solutions were individually diluted to a known volume as required to take any precipitates back into solution. Solids and by-products



HEADSPACE ANALYSIS

Headspace Samples
Crimp-Seal in 10 ml Hypovial 2g of Solids or 2ml of Liquids
Heat Samples in Water Bath at 65°C for 5 minutes
Sulfur Species
Light Hydrocarbons
Is H_2S Expected to be High?
No
Use Direct Injection and Analyze for Sulfur Species
Analyze for Hydrocarbons and Substituted Benzenes
Yes
Dilute Sample for H_2S Analysis
Use Direct Injection But Vent H_2S to Analyze for Other Sulfur Species

Figure 4-11. Flow scheme for the preparation and analysis of headspace samples.

were treated with HNO_3, H_2O_2, and HF as required to digest all residue. The resulting solutions were diluted to a known volume.

The prepared samples in aqueous media were then analyzed according to the following analytical protocols and for the elements listed in Table 4-4.

4.2.5 Water Quality Parameters

Table 4-5 lists the methods used to determine the water quality parameters for aqueous samples. This table also includes the reference for the method and a brief description.

4.2.6 Analysis of Impinger Solutions for Phenols, Ammonia, Hydrogen Cyanide, and Hydrogen Sulfide

The analytical methods used for the analysis of Phenol, NH_3, HCN, and H_2S from impinger solutions are given in Table 4-6. A brief description and reference for these methods is also included in this table.

4.2.7 Analysis of Solids and By-Products

Analytical methods for the analysis of solids and by-products are listed in Table 4-7. A reference for these methods and a brief description are also included.

Analytical reagent blanks were analyzed and used to adjust the raw analytical results from each sample. National Bureau of Standards (NBS) reference materials (coal and ash) were also analyzed using the same procedures. The results were used to assess the accuracy of the analytical results. Duplicate samples were digested (prepared) and analyzed to assure adequate precision. Precision was found to be within 10% for all analyses, and the accuracy, as determined by comparison of NBS reference material analyses, was found to be within 20% of the NBS reported values.

4.2.8 Bioassay Test

Bioassay tests were performed to determine the biological activity of the by-products, solid waste, and solid waste leachates from the Kosovo plant.

The results of these tests indicate the relative level of biological activity of the samples. The activities cannot be used in the same manner as quantative analytical results, but do permit the ranking of streams in terms of their biological activity.

The organic samples that were immiscible with water were extracted with methylene chloride (CH_2Cl_2) and exchanged with dimethylsulfide (DMSO) to prepare them for the in-vitro bioassay tests. The protocol for the extraction and solvent exchange is shown below.

TABLE 4-4. ANALYTICAL METHODS USED FOR THE ANALYSIS OF TRACE ELEMENTS

Element	Method[1]	Description[2]
As	206.2	Atomic Absorption, ETA
Be	210.2	Atomic Absorption, ETA
Cd	213.2/213.1	Atomic Absorption, ETA/DA
Co	219.2	Atomic Absorption, ETA
Cr	218.2/218.1	Atomic Absorption, ETA
Cu	220.1	Atomic Absorption, DA
*Fe	236.2	Atomic Absorption, ETA
Hg	245.2	Atomic Absorption, ETA
No	246.2	Atomic Absorption, ETA
Ni	249.2/249.1	Atomic Absorption, ETA/DA
P	GOST	Colorimetric
Pb	239.2	Atomic Absorption, ETA
Sb	204.2	Atomic Absorption, ETA
Se	270.2	Atomic Absorption, ETA
Sr	PE	Atomic Absorption, ETA
Tl	279.2	Atomic Absorption, ETA
V	286.2	Atomic Absorption, ETA
Zn	289.1	Atomic Absorption, DA

*For metal carbonyl samples only.

[1] Numerical designations refer to (Ref. 4-2) Methods for Chemical Analysis of Water and Wastes (EPA 600-479-020).

[2] ETA - Electro Thermal Atomization

DA - Direct Aspiration

PE - (Ref. 4-3) Analytical Methods for Atomic Absorptpion Spectroscopy, Perkin Elmer.

GOST - (Ref. 4-4) Soviet State Standards Committee Method

TABLE 4-5. ANALYTICAL PROCEDURES FOR WASTE WATERS

Component	Method[1]	Description	References
Waste Waters			
NH_3(free)	Method 418A, 418D	Distillation into boric acid followed by back titration	Ref. 4-5 (418A, 418D)
NH_3(bound)	DIN Method E-5	Kjeldahl reaction plus as above for free NH_3	Ref. 4-6 (E-5)
H_2S	DIN Method G-3	Colorimetric titration of CdS precipitate	Ref. 4-6 (G-3)
F^-	Method 414A, 414C	Distillation followed by colorimetric determination using SPADNS reagent	Ref. 4-5 (414A, 414C)
Cl^-	DIN Method D-1	Titration with mercuric or silver nitrate	Ref. 4-6 (D-1)
NO_3^-	DIN Method D-9	Colorimetric method using chromotropic acid	Ref. 4-6 (D-9)
NO_2^-	DIN Method D-10	Colorimetric method using sulfanilic acid and naphthylamine hydrochloride	Ref. 4-6 (D-10)
COD	Method 508	Reflux with $K_2Cr_2O_7$ and H_2SO_4 and back titrate with $Fe(NH_4)_2(SO_4)_2$	Ref. 4-5 (508)
Permanganate	DIN Method H-4	Acidic and basic reflux with $KMnO_4$, add excess oxalic acid and titrate with $KMnO_4$.	Ref. 4-6 (H-4)
Phenols (volatile)	Method 510A, 510B, and 510C	Spectrophotometric with 4-amino antipyrine	Ref. 4-5 (510A, B and C)
Phenols (non-volatile)	DIN Method H-16	Extraction, convert to phenolates and titration using iodine	Ref. 4-6 (H-16)
Tars and Oils	GOST Method - Tar	Ether extraction between pH 3 and 4 followed by evaporation and weighing (see text)	Ref. 4-4
Dry Solids			
TS (Total Solids)	Method 208	Dry to constant weight at 105°C	Ref. 4-5 (208)
TDS (Total Dissolved Solids)		Filter before drying filtrate	Ref. 4-5
TSS (Total Suspended Solids)		Filter before drying precipitate	Ref. 4-5
pH Value	Method 424	Electrometrically using a glass-reference electrode pair	Ref. 4-5 (424)
Sulfates	Method 427C	Turbidimetric (Not Used)	Ref. 4-5 (427C)
Thiosulfates	GOST Method - Thiosulfates	Iodometric titration	Ref. 4-4 (Thiosulfates)
Rhodanate (CNS^-)	GOST Method - Rhodanate	Colorimetric determination using pyridine and barbituric acid	Ref. 4-4 (Rhodanate)

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[1] DIN-(Ref. 4-6) German Institute for Standardization Method
GOST-(Ref. 4-4) Soviet State Standards Committee Method

TABLE 4-6. ANALYTICAL PROCEDURES FOR IMPINGER SOLUTIONS

Component	Method	Description	References
Phenols	Method 510A, 510B, and 510C	Spectrophotometric with 4-aminoantipyrine dye	Ref. 4-5 (510)
Ammonia	Method 418A, 418D	Distillation of ammonia into boric acid solution with back titration	Ref. 4-5 (418)
HCN	Method 413C	Distillation followed by silver nitrate titration	Ref. 4-5 (413C)
H_2S	ASTM D2035	Iodometric titration of CdS precipitate	Ref. 4-7

TABLE 4-7. ANALYTICAL PROCEDURES FOR SOLIDS AND BY-PRODUCTS

Component	Method	Description	References
Solid Samples			
Moisture	ASTM D3173	Dry to constant weight at 105°C	Ref. 4-8
Ash Content	Method 208 E	Heat at 550°C to constant weight	Ref. 4-5 (208)
Phenols Total Volatile	Method 510A, 510B and 510C	Extraction of solid with acidified water then treat as waste water sample	Ref. 4-5 (510)
Elemental Analysis (C, H, O, N, S)	ASTM D3176	Determination of combustion products	Ref. 4-9

Sample
(4.0 mL or 4.0 gm)
↓
Add 35 mL CH_2Cl_2
↓
Shake several hours at room temperature
↓
Shake 1 part CH_2Cl_2 phase with 1 part DMSO
↓
Evaporate CH_2Cl_2 with N_2 Stream at 40°C for 7 hours
↓
Add DMSO to bring final volume to 40 mL
↓
Prepare serial dilution with DMSO as required for
in-vitro bioassays

Salmonella Bacterial Mutagenicity Assay (Ames')

The Ames' assay is based on the ability of selected mutant strains of *Salmonella typhimurium* to revert from histidine dependence to prototrophy (the ability to synthesize nutriments, in this case histidine, from inorganic materials in the medium) upon exposure to various mutagens and carcinogens. Though the assay does not use mammalian cells it may be adapted to mimic some mammalian metabolic processes by the addition of mammalian (rat) liver microsomes to the system (metabolic activation).

The assay is conducted in a culture medium containing insufficient histidine to allow the tester strains to proliferate. The tester organisms, with and without the microsome preparation, are mixed with the test materials in molten top agar and poured on plates over a selective basal medium. The test plates, with positive, negative, sterility and activation control plates, are incubated for 48 hours at 37°C.

Mutation is indicated by the appearance of colonies. Results are reported as the total number of revertants (colonies) per plate. A ratio of experimental over control (spontaneous) revertants of 2.0 or greater is generally considered evidence of the mutagenicity of the test material.

In-Vitro Cytotoxicity Assay (RAM and CHO)

Cytoxicity assays employ mammalian cells in culture to measure quantitatively and cellular metabolic impairment and/or death resulting from exposure in-vitro to soluble or particulate toxic material. A primary culture of rabbit alveolar (lung) macrophages (RAM) was used to determine the in-vitro toxicity of the solid waste (slag or gasifier ash) from the Kosovo gasifiers. Chinese hamster ovary (CHO) fibroblasts were used to determine in-vitro toxicity by clonal assay of the liquid samples.

Alevolar macrophages constitute the body's first line of pulmonary defense against particulate matter deposited deep in the lung. Thus, it is appropriate that such cells be used to assay the acute cellular toxicity of airborne particulates and associated chemical species.

A primary RAM suspension was collected by lung lavage with five instillation volumes of 30 cm^3 of 37°C sterile 0.9 percent physiological saline solution (PSS). The cells were washed once by centrifugation and resuspended in fresh PSS. Cell viability was determined and the cells were recentrifuged, suspended in culture medium, diluted, combined with the test material, (or control) and incubated at 37°C (humidified five percent CO_2 atmosphere) for 20 hours. Following incubation, cell viability, total protein and ATP content were determined.

CHO fibroblasts were removed from liquid nitrogen storage and maintained as a monolayer culture for slightly over one month until required for the assay. In the assay, CHO cells were suspended in medium, dispensed into tissue culture flasks or dishes, and allowed to adhere for six hours. The medium was then aspirated and replaced with medium containing sample at an appropriate dilution. Positive ($NaNO_2$ treated), negative (untreated), and vehicle (DMSO) controls were also prepared.

After incubation for 24 hours, all flasks or dishes were washed with three aliquots of phosphate buffered saline (PBS) and re-covered with medium. The cells were then incubated for six days to allow clones to develop, after which they were drained, washed, fixed, stained, and the clones counted.

Acute in-Vitro Toxicity in Rodents

Five male and five female mice (Strain DF) of comparable body weights were selected, from a group held in quarantine, for testing each sample. All animals selected appeared to be healthy.

Test material (samples) was administered, without dilution, by direct introduction into the stomach of the animal (gavage) as a single dose. Control animals were treated by administering doses of material used as vehicles for the ash (KY lubricant) and heavy tar and dust (trioctanion).

Body weights were recorded at the time of dosing, Day 1, Day 8 and Day 15. Animals were observed daily for signs of poor health. A gross autopsy was performed on each animal at death or at sacrifice (Day 15). Organ weights were not obtained.

4.3 DATA EVALUATION - SOURCE ANALYSIS MODEL/1A

The Source Analysis Model/1A (SAM/1A) is U.S. EPA-IERL's method for evaluation of discharge stream data. Its principle strength is that it makes possible the reduction of pollutant discharge data to a common numerical base so that discharges can be ranked or prioritized objectively.

The SAM/1A is based on multimedia environmental goals, or MEGs, which are used to compute a Discharge Severity (DS). MEG is defined as a "concentration level below which the discharged component is of low concern for its potential effects on either human health or the ecology" (Ref. 4-10). In this respect, it is a "target value" for components in discharge streams. MEGs have been defined for many substances representing 26 classes of organic compounds (Ref. 4-11). Target levels have been defined in terms of their effect on both human health and ecology for discharges to the three environmental media: air, water, and soil. The goals set for discharges are named "Discharge Multimedia Environmental Goals" or DMEGs. DMEG (Air-Health) values for sixteen components whose discharge stream concentrations were measured in this study are shown graphically in Figure 4-12. A reciprocal of DMEG is plotted since DS is the product of concentration and 1/DMEG as defined below.

$$\mathrm{DS} = \frac{\text{Measured Concentration of a Pollutant}}{\text{DMEG of that Pollutant}}$$

The DMEG, therefore, serves as a common denominator which reduces all components to a common base, i.e., "multiples of the target value". The DS calculated in this manner is a dimensionless number (or at least it is reduced to the common dimension - multiple of target value) which can be summed. Consequently, a stream's discharge severity can be determined by summing the DS's for all components in that stream to determine the Total Discharge Severity (TDS):

$$\mathrm{TDS} = \Sigma \mathrm{DS}$$

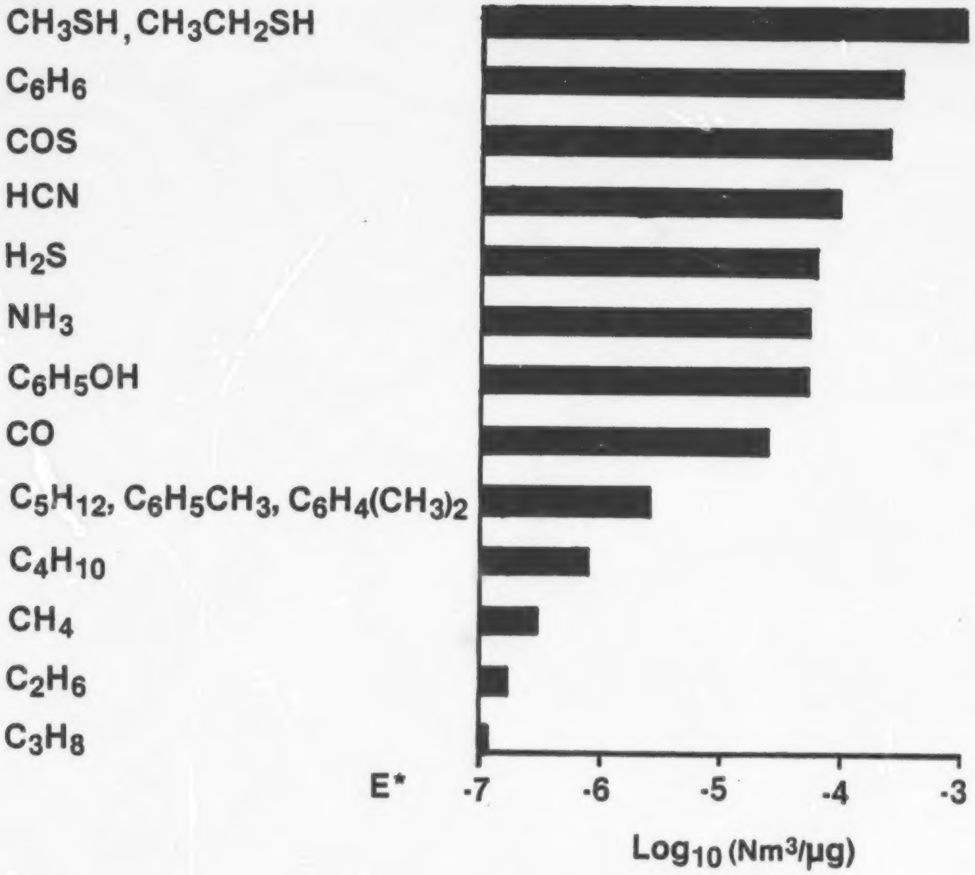
The TDS value provides a basis for comparing discharge streams, and, therefore, provides a basis for identifying the most severe streams.

Discharge severity is a concentration of a composition-based value that does not define the quantity of mass emitted. Used alone, it cannot define the environmental effects of a discharge bcause such effects are related to both quantity and severity. With the SAM/1A Model, the significance of a pollutant discharge in a given stream is defined by its Weighted Discharge Severity (WDS):

$$\mathrm{WDS} = \mathrm{mr} \cdot \mathrm{DS}$$

where mr = Stream Mass Flow Rate;

and further, the environmental significance of that discharge stream is defined by its Total Weighted Discharge Severity;



E* = Exponential (E-5 = 10^{-5})

Figure 4-12. Key Kosovo gaseous pollutants in order of severity (1/DMEG).

$$TWDS = mr \quad \Sigma DS = mr \cdot TDS$$

By comparing discharge streams within a given medium, such as air, water, or land, the stream with the highest TWDS value may be selected as the most significant environmentally.

Major simplifying assumptions implicit in the use of the Source Analysis Model/1A (SAM/1A) methodology are:

- The substances currently in the Multimedia Environmental Goals (MEG) lists (Ref. 4-10, 4-11, 4-12 and 4-13) plus the communication in Appendix D (supercedes all previous values) are the only ones that must be addressed at this time (the MEGs are currently being updated to include new data, account for new or revised standards, and new compounds).
- Transport of the components in the waste streams to the external environment occurs without chemical or physical transformation of those components.
- Actual dispersion of the pollutant from a source to a receptor will be equal to, or exceed that assumed when MEG values are estimated from acute toxicity data.
- Discharge Multimedia Environmental Goals (DMEG) values (Ref. 4-10, 4-11, 4-12 and 4-13) developed for each substance are adequate for estimating acute toxicity. A DMEG is a concentration of a substance estimated to cause an adverse effect in a receptor exposed once or intermittently for short periods. It relates either to human health or ecological effect.
- The waste stream components are neither synergistic nor antagonistic.

These assumptions, along with the accuracy of the test data, must be considered when interpreting test results presented in this report based on the SAM/1A data evaluation scheme.

SECTION 5

RESULTS AND DISCUSSION

The results obtained from this study consist of stream composition and flow data. All results are contained in Appendix A. In this section, attention is given to the interpretation of these results. All calculations and interpretations are based on the "best values" as listed in Appendix A. The "best values" were selected based on scientific and engineering judgment. For example, if two sets of composition data exist for a stream, and the plant was not operating under stable conditions when one set was obtained, the other set is listed as the best value.

Stream concentration values were obtained on-site during the tests in a form for rapid interpretation. For example, gas stream composition was expressed in volume or mole percent so that components could be summed for accountability. To evaluate streams as discharges, it is more useful to express the values in terms of mass concentration (e.g., $\mu g/m^3$) which is easily converted into mass flow rate.

The discharges were evaluated in terms of discharge severity according to the model SAM/1A. The concepts and methods of this model were discussed in Section 4.

This section is divided into the following subsections:

- gaseous discharges,
- aqueous discharges,
- solid discharges, including a comparison to gaseous and aqueous discharges,
- products and by-products,
- bioassay results,
- mass balances, and
- additional comments and summary of findings.

5.1 GASEOUS DISCHARGE STREAMS

Much of the data from the tests at the Kosovo Plant are for components of gaseous discharge streams. This is due to the large number of gaseous discharge streams and their potential environmental significance. All major and many minor gaseous components were measured, including particulate loading on selected streams. The following discussion will show that stream composition followed a logical pattern through the plant and that all gaseous discharge streams are of significant environmental concern, according to the results of SAM/1A modeling.

5.1.1 Composition of the Gaseous Discharges

Each section of the gasification plant has characteristic concentrations of components in the discharge streams. In order to easily compare composition data, Table 5-1 contains a summary of best values for selected gaseous discharge streams. The sum of the volume percent at the time of the analyses gave a rapid method of accounting for the major components. The average of the sums of the volume percent for the twelve streams in Table 5-1 on which fixed gases were determined (Stream 14.5 is normalized) is 96%.

Autoclave Vent (1.2) composition data indicate that the Fleissner (steam drying) Process produces small amounts of gaseous species, such as hydrogen sulfide, methyl mercaptan, ethyl mercaptan and benzene. The stream has a high concentration of steam (76% moisture by volume).

The gaseous discharge streams (3.2 and 3.6) from the gas production section listed in Table 5-1 show similar compositions except for the high level of ammonia found in the low pressure coal lock vent (3.2). The ammonia is probably recovered from this stream by the high pressure coal lock vent scrubber before it is discharged. As expected, the H_2S-rich waste gas stream (7.1) in the Rectisol section has the highest concentrations of H_2S of any gaseous stream at Kosovo. A comparison of H_2S levels in 7.1 and 7.2 indicates that the majority of the H_2S is removed from the product gas stream in the first step of the Rectisol process (by a discrimination factor of over 1000 to 1 over the second step).

Even though tank vents have much lower flow rates than such large discharge streams as 7.1 and 7.2, their composition data indicate important information from an environmental viewpoint. Furthermore, these vents may pose a difficult control problem due to the large number of vents and the varying composition of the vent gases. For example, the naphtha storage tank vent stream (15.3) has about 4% benzene; methyl and ethyl mercaptans were found at relatively high levels. Internal consistency of composition data for the gaseous streams is exemplified by the C_6+ value of 5.3% which is slightly greater than benzene plus toluene at 3.9%.

In the Phenosolvan Process, the NH_3 stripper vent stream (14.5) had an ammonia concentration of 42% by volume (during this study ammonia was not being recovered, but was being discharged to the atmosphere). Furthermore, this stream has relatively high concentrations of HCN, phenols, and H_2S.

The volume percent data in Table 5-1 is converted to mass concentrations ($\mu g/m^3$) in Table 5-2. From mass concentration, mass discharge rates can be calculated using flow rates. The sums of the mass discharges plantwide for all the gaseous species measured during the tests are listed in Table 5-3. These discharge rates are based on one gasifier in operation. In Table 5-3, CO_2 is the largest discharge based on mass. It's discharge rate is 12,300 kg/gasifier-hr. Most of the CO_2 leaves the plant in streams 7.1 and 7.2 (Table 5-2). The C_1-C_6 hydrocarbons and the combined sulfur species have discharges between 200-400 kg/gasifier-hr. Mass discharge rates for CO and NH_3 fall in the range of approximately 80 kg/gasifier-hr. The discharges of CO are dominated by gas production section streams 3.2 and 3.6 as listed in Table 5-2; the Ammonia Stripper Vent (14.5) accounts for 90% of the ammonia discharged plantwide.

TABLE 5-1. KOSOVO GASEOUS STREAM COMPOSITION DATA

PLANT SECTION:	Fleissner Drier	Gas Production			Rectisol	
SAMPLE POINT:	1.2 Autoclave Vent	3.2 Low Pressure Coal Lock Vent	3.4 Gas Liquor Tank Vent	3.6 High Pressure Coal Lock (Flare Feed Stream)	7.1 H_2S-rich Waste Gas (Flare Feed Stream)	7.2 CO_2-rich Waste Gas
Dry Gas Flow Rate (m^3/gasifier-hr @25°C)	57.8	21	44	230	3600	3600
Temperature (°C)	-	56	60	54	12	19
Moisture Content (%)	76	44	-	11	3.9	5.1
Molecular Wt. of Dry Gas	33.4	23.5	-	24.9	43.0	42.2
Composition (Dry Basis)						
Fixed Gases (Vol %)						
H_2	Tr	37	12	32	0.11	Tr
O_2	14	0.27	14	0.24	Tr	Tr
N_2	56	0.18	56	0.14	Tr	Tr
CH_4	Tr	8.6	-	10.5	4.3	1.2
CO	Tr	14.6	2.6	12	1.1	Tr
CO_2	29	36.5	-	42	88	94
Sulfur Species (ppmv)						
H_2S	2,400	13,000	1,450	3,500	45,400	39
COS	30	110	-	120	420	62
CH_3SH	3,400	420	-	460	2,100	8.5
C_2H_5SH	2,100	220	-	210	780	4.4
Hydrocarbons (Vol %)						
C_2H_6	Tr	0.22	-	0.42	0.82	1.6
C_2H_4	NF	Tr	-	Tr	Tr	Tr
C_3's	0.03	0.14	-	0.25	0.63	0.28
C_4's	0.03	0.05	-	0.11	0.32	Tr
C_5's	NF	Tr	-	0.01	0.04	Tr
C_6+	0.011	0.12	-	0.08	0.21	NF
Aromatic Hydrocarbons (ppmv)						
Benzene	17	760	-	550	110	1.0
Toluene	6.8	220	-	100	8	Tr
Xylene & Ethylbenzene	4.2	75	-	38	Tr	Tr
Phenols	-	5.7	Tr	2.5	NF	NF
Higher Aromatics	-	-	-	-	-	-
Nitrogen Species (ppmv)						
NH_3	-	2,400	690	NF	2,200	4.6
HCN	-	600	-	170	200	13

Tr - Trace = 0.01 vol % for fixed gases, 1 ppmv for all others.
NF - Not Found = less than a trace

(Continued)

TABLE 5-1. (Continued)

PLANT SECTION:	Tank Separation					Phenosolvan		By-Product Storage
SAMPLE POINT:	13.1 Tar Tank Vent	13.3 Medium Oil Tank Vent	13.5 Condensate Tank Vent	13.6 Tar Separation Waste Gas (Flare Feed Stream)	13.7 Phenolic Water Tank Vent	14.5 NH_3 Stripper Vent	14.6 Cooler Vent	15.3 Naphtha Storage Tank Vent
Dry Gas Flow Rate (m^3/gasifier-hr @25°C)	0.55	1.7	3.38	28	5.5	260	4.4	4.5
Temperature (°C)	52	42	7	40	76	91	-	32
Moisture Content (%)	14	8.4	~1.0	7.7	42	76	-	5
Molecular Weight of Dry Gas	29.1	32.5	26.6	39.0	34.4	32.7	-	33.3
Composition (Dry Basis)								
Fixed Gases (Vol %)								
H_2	Tr	Tr	14.6	11	Tr	NF	-	NF
O_2	19	0.45	16.6	Tr	13	-	-	2.6
N_2	77.5	1.1	61.0	Tr	39	-	-	84
CH_4	0.16	7.6	1.2	3.5	0.2	Tr	-	NF
CO	Tr	5.9	NF	1.1	NF	NF	-	NF
CO_2	0.86	56	6.2	77.5	35	55	-	0.85
Sulfur Species (ppmv)								
H_2S	6900	26,000	6,200	9,000	12,600	19,500	Tr	NF
COS	110	96	-	120	41	NF	-	NF
CH_3SH	390	5200	210	2,500	2,100	290	-	2.600
C_2H_5SH	240	2100	72	1,600	7,200	100	-	9.700
Hydrocarbons (Vol %)								
C_2H_6	Tr	0.34	0.07	0.33	0.02	Tr	-	Tr
C_2H_4	-	Tr		Tr			-	-
C_3's	0.01	0.30	0.05	0.41	0.02	Tr	-	0.01
C_4's	Tr	0.25	0.03	0.41	0.02	Tr	-	0.07
C_5's	Tr	0.09	0.04	0.09	0.006	Tr	-	0.08
C_6+	0.37	2.4	-	1.3	1.8	NF		5.3
Aromatic Hydrocarbons (ppmv)								
Benzene	2,000	7,650	5,200	9,600	11,000	-	-	37,600
Toluene	960	1,400	3,000	1,200	2,300	-	-	1,900
Xylene & Ethylbenzene	220	140	-	150	280	Tr	-	60
Phenols	57	110	Tr	4.2	Tr	6,200	Tr	Tr
Higher Aromatics	2.2	-	-	4.9	3.1	-	-	-
Nitrogen Species (ppmv)								
NH_3	2,600	19	NF	19,300	12,000	418,000	82,000	NF
HCN	130	57	170	64	38	4,800	-	1,100

Tr - Trace = 0.01 vol % for fixed gases, 1 ppmv for all others.
NF - Not Found = less than a trace.

TABLE 5-2. COMPONENT CONCENTRATIONS IN KOSOVO GASEOUS STREAMS

PLANT SECTION:	**Fleissner Drier**	**Gas Production**			**Rectisol**	
SAMPLE POINT:	1.2 Autoclave Vent	3.2 Low Pressure Coal Lock Vent	3.4 Gas Liquor Tank Vent	3.6 High Pressure Coal Lock (Flare Feed Stream)	7.1 H_2S-rich Waste Gas (Flare Feed Stream)	7.2 CO_2-rich Waste Gas
Component (μg/m³ @ 25°C)						
Fixed Gases						
H_2	Tr	3.05 E07	9.74 E06	2.64 E07	8.98 E04	Tr
O_2	1.83 E08	3.53 E06	1.81 E08	3.14 E06	Tr	Tr
N_2	6.41 E08	2.06 E06	6.35 E08	1.60 E06	Tr	Tr
CH_4	Tr	5.64 E07	-	6.88 E07	2.82 E07	7.84 E06
CO	Tr	1.67 E08	2.97 E07	1.37 E08	1.26 E07	Tr
CO_2	5.21 E08	6.56 E08	-	7.55 E08	1.58 E09	1.69 E09
Sulfur Species						
H_2S	3.34 E06	1.80 E07	2.02 E06	4.87 E06	6.32 E07	5.43 E04
COS	7.36 E04	2.70 E05	-	2.95 E05	1.03 E06	1.52 E05
CH_3SH	6.68 E06	8.25 E05	-	9.04 E05	4.13 E06	1.67 E04
C_2H_5SH	5.33 E06	5.57 E05	-	5.35 E05	1.98 E06	1.12 E04
Hydrocarbons						
C_2H_6	Tr	2.96 E06	-	5.16 E06	1.01 E07	1.97 E07
C_2H_4	NF	Tr	-	Tr	Tr	Tr
C_3's	5.40 E05	2.52 E06	-	4.50 E06	1.14 E07	5.04 E06
C_4's	7.14 E05	1.19 E06	-	2.61 E06	7.60 E06	Tr
C_5's	NF	Tr	-	2.95 E05	1.18 E06	Tr
C_6+	3.43 E05	4.22 E06	-	2.82 E06	7.39 E06	NF
Benzene	5.44 E04	2.43 E06	-	1.76 E06	3.51 E05	3.19 E03
Toluene	2.56 E04	8.28 E05	-	3.76 E05	3.00 E04	Tr
Xylene & Ethylbenzene	1.82 E04	3.25 E05	-	1.65 E05	NF	Tr
Phenols	-	2.19 E04	Tr	9.61 E03	Tr	NF
Nitrogen Species						
NH_3	-	1.73 E06	4.80 E05	NF	1.53 E06	3.20 E04
HCN	-	6.62 E05	-	1.88 E05	2.21 E05	1.44 E04
Dry Gas Flow Rate (m³/gasifier-hr @25°C)	57.8	21	44	230	3,600	3,600

NF = Not Found
Tr = Trace

(Continued)

TABLE 5-2. (Continued)

PLANT SECTION:	**Tank Separation**					**Phenosolvan**		**By-Product Storage**
SAMPLE POINT:	**13.1 Tar Tank Vent**	**13.3 Medium Oil Tank Vent**	**13.5 Condensate Tank Vent**	**13.6 Tar Separation Waste Gas (Flare Feed Stream)**	**13.7 Phenolic Water Tank Vent**	**14.5 NH_3 Stripper Vent**	**14.6 Cooler Vent**	**15.3 Naphtha Storage Tank Vent**
Component ($\mu g/m^3$ @ 25°C)								
Fixed Gases								
H_2	Tr	Tr	1.20 E07	8.98 E06	Tr	NF	-	NF
O_2	2.48 E08	5.88 E06	2.16 E08	Tr	1.70 E08	-	-	3.40 E07
N_2	8.87 E08	1.26 E07	6.95 E08	Tr	4.46 E08	-	-	9.61 E08
CH_4	1.04 E06	4.98 E07	7.84 E06	2.29 E07	1.31 E06	Tr	-	NF
CO	Tr	6.75 E07	NF	1.26 E07	NF	NF	-	NF
CO_2	1.55 E07	1.01 E09	1.11 E08	1.40 E09	6.29 E08	9.89 E08	-	1.53 E07
Sulfur Species								
H_2S_6	9.61 E06	3.62 E07	8.61 E06	1.25 E07	1.75 E07	2.72 E07	NF	NF
COS	2.70 E05	2.36 E05	-	2.94 E05	1.01 E05	NF	-	NF
CH_3SH	7.66 E05	1.02 E07	4.11 E05	4.91 E06	4.13 E06	5.70 E05	-	5.11 E06
C_2H_5SH	6.09 E06	5.33 E06	1.82 E05	4.06 E06	1.83 E07	2.54 E05	-	2.46 E07
Hydrocarbons								
C_2H_6	Tr	4.18 E06	8.57 E05	4.05 E06	2.46 E05	Tr	-	Tr
C_2H_4	-	Tr		Tr	-	-	-	-
C_3's	1.80 E05	5.40 E06	9.01 E05	7.39 E06	3.60 E05	Tr	-	1.80 E05
C_4's	Tr	5.94 E06	7.13 E05	9.74 E06	4.75 E05	Tr	-	1.66 E06
C_5'	Tr	2.65 E06	1.18 E06	2.65 E06	1.77 E05	Tr	-	2.36 E06
C_6+	1.30 E07	8.45 E07	-	4.58 E07	6.34 E07	NF	-	1.87 E08
Benzene	6.38 E06	2.44 E07	1.66 E07	3.06 E07	3.51 E07	Tr	-	1.20 E08
Toluene	3.61 E06	5.27 E06	1.13 E07	4.52 E06	8.66 E06	-	-	7.15 E06
Xylene & Ethylbenzene	9.52 E05	6.06 E05	-	6.51 E05	1.21 E06	Tr	-	2.60 E05
Phenols	2.19 E05	1.73 E05	Tr	1.62 E04	Tr	2.38 E07	Tr	Tr
Nitrogen								
NH_3	1.81 E06	1.32 E04	NF	1.34 E07	8.35 E06	2.91 E08	5.71 E07	NF
HCN	1.44 E05	6.28 E04	1.88 E05	7.05 E04	4.20 E04	5.30 E06	-	1.21 E06
Dry Gas Flow Rate (m^3/gasifier-hr @ 25°C)	0.55	1.7	3.38	28	5.5	260	4.4	4.5

NF = Not Found
Tr = Trace

TABLE 5-3. MOST SIGNIFICANT GASEOUS SPECIES IN ORDER OF MASS DISCHARGE - PLANTWIDE

Ranking*	Species	Discharge g/s (kg/hr)**	Ranking	Species	Discharge
1	CO_2	3420 (12,300)	9	C_4's (as C_4H_{10})	7.9 (28.3)
-	$\Sigma(C_1-C_6)$	106 (380)	10	CH_3SH	4.4 (15.8)
-	Σ(sulfur species)	73 (261)	11	C_2H_5SH	2.2 (7.99)
2	H_2S	66 (237)	12	Phenols	1.7 (6.19)
3	CH_4	41 (148)	13	C_5's (as C_5H_{12})	1.2 (4.42)
4	C_2H_6	30 (109)	14	COS	1.2 (4.34)
5	CO	23 (82.1)	15	Benzene	0.94 (3.37)
6	NH_3	23 (81.8)	16	HCN	0.64 (2.29)
7	C_3's (as C_3H_8)	17 (60.5)	17	Toluene	0.12 (0.443)
8	C_6^+ (as C_6H_{14})	8.3 (29.9)	18	Xylenes and Ethylbenzene	0.026 (0.0938)

*Ranking based on individual species.
**grams/gasifier-second (kg/gasifier-hour).

5.1.2 Discharge Severities of Gaseous Discharges

The mass concentrations of the components of each discharge stream can be used to calculate a discharge severity following EPA's IERL Source Analysis Model/1A (SAM/1A) as outlined in Section 4.

The low pressure coal lock vent (3.2) will be used to illustrate the effects of converting concentrations to discharge severities (DS's). In Figure 5-1 the mass concentration of the major pollutants in the coal lock vent discharge can be compared with their DS values. Note that benzene and mercaptans, which are at relatively low concentrations, emerge as pollutants of high concern. Trace elements listed in Appendix C were considered, but their DS values were relatively low compared to the compounds listed in Figure 5-1. This conclusion is true for trace elements in all gaseous streams.

Since the DS values can be summed, a single value can be obtained which provides a numerical indication of stream severity in terms of concern for causing adverse health effects. Total discharge severity values of the most significant gaseous streams are compared in Figure 5-2. The degree of concern for all the streams listed is two to four orders of magnitude above the level where concern begins (DS>1) as defined by the SAM/1A model. The fourteen streams listed in Figure 5-2 include at least one stream from every section in the plant. The TDS gives an idea of stream severity; however, flow must be coupled with TDS (=TWDS) to give an indication of environmental burden from the discharge streams as illustrated in Figure 5-2.

As an example of what happens when flow is considered, the naphtha storage tank vent (15.3) and the CO_2-rich waste gas (7.2) are compared. Since the values in Figure 5-2 are in exponential form, the addition of $\log_{10}$ flow to the $\log_{10}$ TDS gives the $\log_{10}$ of the Total Weighted Discharge Severity (TWDS). The TDS of the naphtha storage tank and CO_2-rich waste gas are 7.08 E+04 and 2.69 E+02 respectively. From this comparison it is evident that the discharge from the naphtha storage tank is several hundred times more severe than the discharge from the CO_2-rich waste gas vent. However, when the flow rates of the respective streams are taken into consideration, the two streams are of virtually equal environmental significance.

In Figure 5-2 the streams are ranked according to their environmental impact on health (SAM/1A). This comparison is illustrated using the height of each column. The H_2S-rich waste gas (7.1) has the highest TWDS, in the range of E+07. The ammonia stripper vent (14.5) is an order of magnitude below 7.1. The next seven streams in descending order are 7.2, 3.6, 1.2, 13.6, 15.3, 3.2, and 13.7); they have TWDS values in the range of E+05.

Since the SAM/1A treatment can also be used to relate stream composition and flow rate to ecological effects, the health values cited above can be compared to the ecology values as they are in Figure 5-3. As shown in the figure, a reordering of the discharge streams occurs. The ammonia stripper vent (14.5) has the highest ecological TWDS values, in the range of E+08. This increase is due primarily to the NH_3 content of the stream. The H_2S-

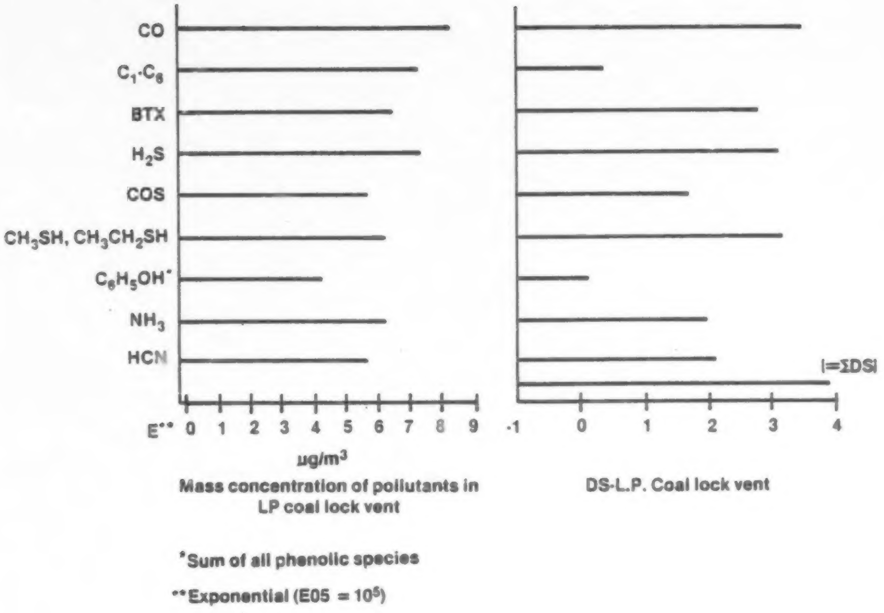


Figure 5-1. Comparison of mass concentrations to discharge severities (air-health) in the low pressure coal lock vent discharge stream (3.2).

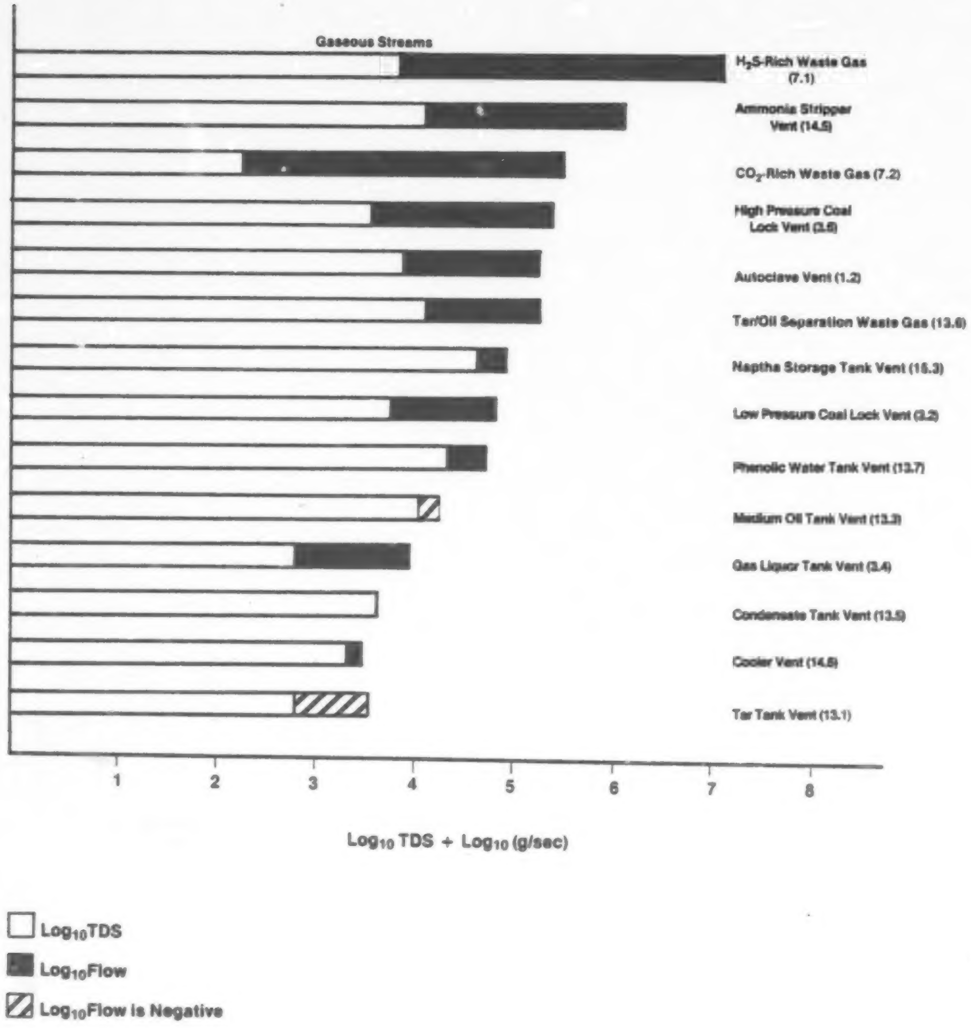


Figure 5-2. Total weighted discharge severities (air-health) of key Kosovo gaseous discharge streams.

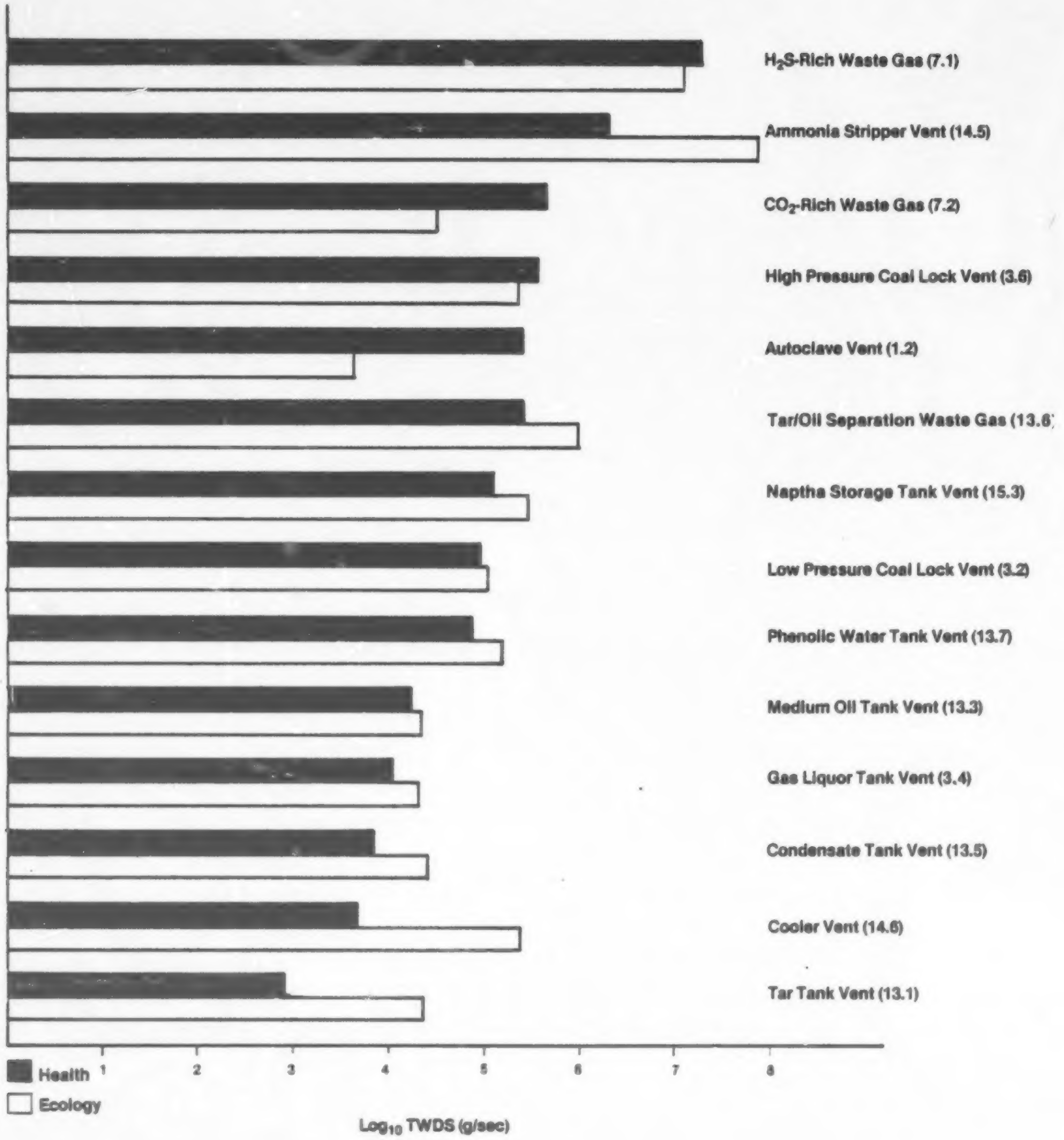


Figure 5-3. A comparison of health and ecology total weighed discharge severity values in key Kosovo gaseous discharge streams.

rich waste gas (7.1) has the second largest ecological TWDS value, 1.3 E+07. Several streams such as 14.6 and 13.1 also have significantly higher values for ecological TWDS than for health TWDS. This is caused by a greater concern for the effects of NH_3 on the ecology than on health.

The stream having a significantly lower ecological TWDS value than health TWDS value is the Fleissner autoclave vent. Its value drops from 2.60 E+05 (health) to 4.65 E+03 (ecology). This reduction is due primarily to the lack of values for methyl and ethyl mercaptans in the ecology MEG data base for the SAM/1A model.

The ranking of individual chemical species on a plantwide basis using the SAM/1A treatment is of interest. Figure 5-4 shows the nine worst chemical species in the Kosovo gaseous streams, in order of descending TWDS (health values). The sulfur species, H_2S, CH_3SH and C_2H_5SH, are of highest concern in order of descending TWDS's. Ammonia and CO are of next highest concern and are about an order of magnitude less than the sulfur species. COS, benzene, HCN and phenols round out the top nine species of highest concern.

5.1.3 Particulate Data

Particulate loadings were obtained for seven gaseous discharge streams. The particulate catch was divided into three parts: extractable organics (tars and oils), filterable solids and dissolved solids. Data for the seven discharge streams are listed in Table 5-4. This discussion focuses on the results from particulate catches obtained by the impinger method (see Section 4.1.5) and specifically on the results from particulates found in the low pressure coal lock vent gases (3.2). This stream is emphasized because of the potential environmental significance of the particulates that are transported with the gas discharged through this vent.

A major portion of the Kosovo particulate catch consists of condensed organics (tar and oil) as tabulated below:

	Tars and Oils (wt %)
Autoclave Vent (1.2)	44
LP Coal Lock Vent (3.2)	90
Start-up Gas Vent (3.3)	95
HP Coal Lock Vent (3.6)	69
Tar/Oil Separation Waste Gases (13.6)	72
Combined Gases to Flare (20.1)	76

Analytical results are not yet available from the collections. Therefore, byproduct composition data were used to make judgments about the significance of these particulates. Particular attention was directed to the LP coal lock vent gas since it is discharged to the atmosphere at Kosovo and a similar arrangement is proposed at several conceptual U.S. plants. The LP coal lock vent discharge contained 8.1 E+03 mg/m^3 of particulates of which 7.8 E+03 mg/m^3 were tars and oils. Table 5-5 shows the concentrations of several of

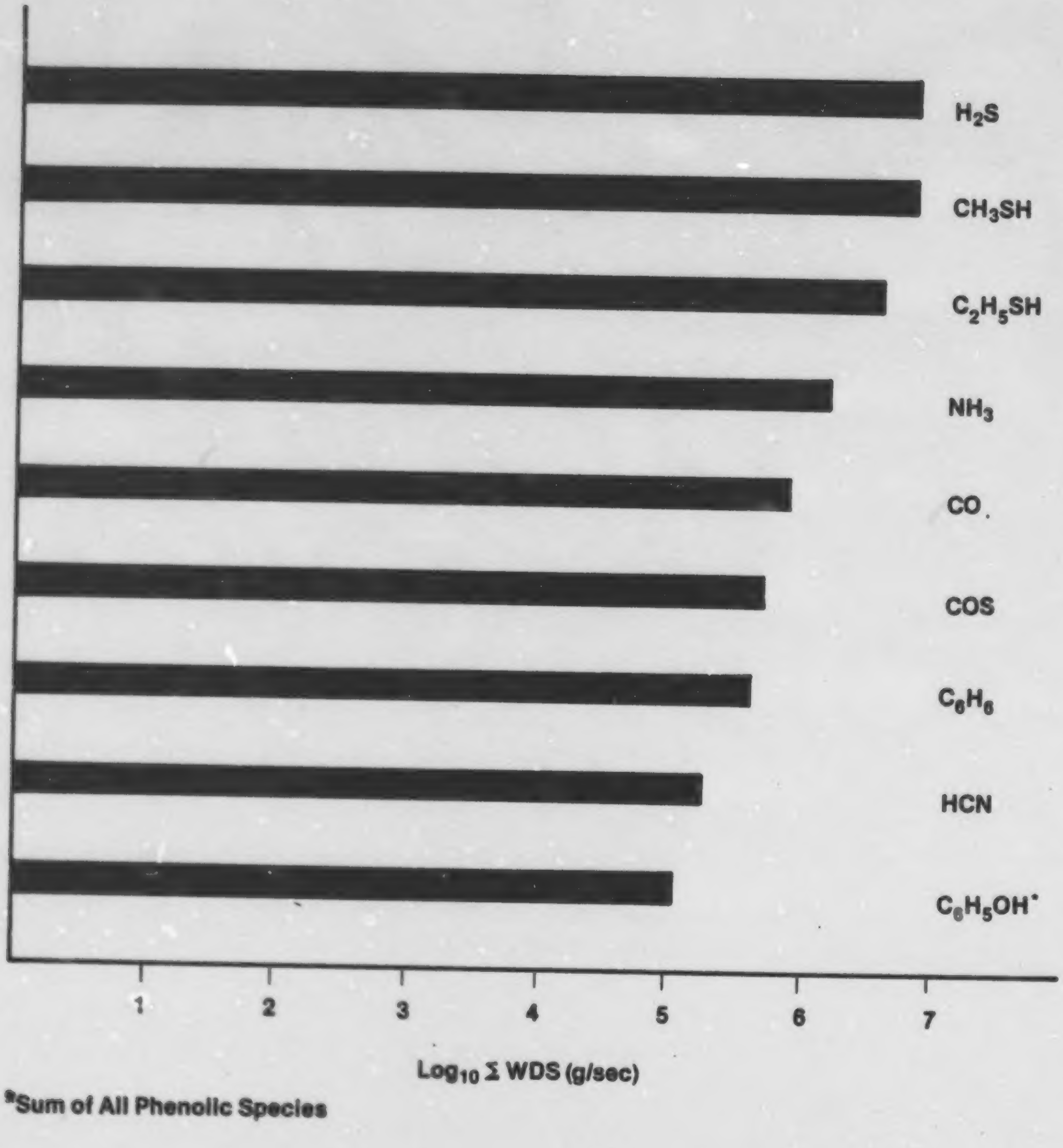


Figure 5-4. The nine worst compounds in gaseous discharge streams on a plantwide basisi in order of descending TWDS (health).

TABLE 5-4. PARTICULATE CONCENTRATION AND FLOW RATE DATA FOR KOSOVO GASEOUS STREAMS

SAMPLE POINTS: STREAM DESCRIPTION:	1.2 Autoclave Vent	2.2 Coal Room Vent	3.2 Low Pressure Coal Lock Vent	3.3 Gasifier Start-Up Vent	3.6 High Pressure Coal Lock Vent	13.6 Tar/Oil Separation Waste Gas	20.1* Combined Gases To Flare
Dry Gas Flow Rate (m_3/gasifier-hr @ 25°C)	57.8	7200	21	-	230	28	1330
Total Particulate (mg/m^3 @ 25°C)	1080	90	8100	9450	960	920	410
Condensed Organics (Tars & Oils)	480	-	7300	8980	660	660	310
Dissolved Solids	320		650	400	240	230	54
Filtered Solids	280		220	61	61	29	47

*The streams that make up 20.1 are discussed individually since in a U.S. Plant different streams may be sent to the flare.

TABLE 5-5. HAZARDOUS PNA'S IN KOSOVO LIGHT TAR AND MEDIUM OIL (μg/g)

	Light Tar	Medium Oil
7,12-Dimethylbenz(a)anthracene	1100	62
Benz(a)anthracene	490	160
Benzo(b)fluroanthene	310	120
Benzo(a)pyrene (BaP)	210	68
Benzo(a,h)anthracene	23	7
3-Methylcholanthrene	26	NF
252 Group	950*	280 *

*BaP - 24% of 252 Group in both by-products.

the most severe polynuclear aromatics (PNA's) contained in the by-product light tar and medium oil discharged as an aerosol is the same as that in the light tar and medium oil by-products, it is reasonable to assume that the PNA level in the aerosol (particulates) would be in proportion to the amount of light tar and medium oil found there. Consider the following data:

LP Coal Lock Vent	$\mu g/m^3$	$\mu g/hr$
Particulate Concentration	8.1 E+06	1.7 E+08
Tar and Oil	7.3 E+06	1.5 E+08
Benzo(a)pyrene-based on tar	1.5 E+03	3.2 E+04
Benzo(a)pyrene-based on oil	5.0 E+02	1.0 E+04

These results imply that the level of benzo(a)pyrene in the LP coal lock vent discharge is in the range of 500 to 1,600 ug/m^3. The levels of all other PNA's may be estimated in the same manner.

The presence of PNA's in the LP coal lock vent discharge increases the TDS of that stream significantly. The effect of the increase using the average PNA content of light tar and medium oil is shown in Figure 5-5. Note that the increase in TDS resulting from the inclusion of PNA data elevates the LP coal lock vent to almost the same level of significance as the ammonia stripper vent (14.5) at 2 E+06. The three other streams in Figure 5-5 are changed only slightly by the contribution of the PNA's.

5.2 AQUEOUS WASTE STREAMS

All aqueous stream data are listed in Appendix A. The two major aqueous waste streams in the Kosovo Gasification plant are:

- Gasification section waste water, which is a combination of the following streams:
  - ash quench water,
  - coal bunker vent gas scrubber blowdown, and
  - ash lock vent gas scrubber blowdown; and
- Phenosolvan wastewater.

Water quality data and concentrations of anions and polynuclear aromatics are listed in Table 5-6 for the gasification section wastewater and Phenosolvan inlet and outlet streams. Both wastewaters have high values for solids, COD and permanganate values. Effluent Guidelines set for Steam Electric Power Generation (Ref. 5-1) limit the pH of an aqueous discharge to a range of 6.0 to 9.0 and total suspended solids (TSS) to 100 mg/L maximum during any one day. Both limits are exceeded by the phenolic water Phenosolvan wastewater and the TSS level is exceeded by the gasification section wastewater. The high pH is due to the alkaline nature of the Kosovo lignite ash. For the trace elements measured in the Phenosolvan inlet (14.0) the Effluent Guidelines are not exceeded (Zn = 1.0 mg/L, Cr = 0.2 mg/L and P = 5.0 mg/L).

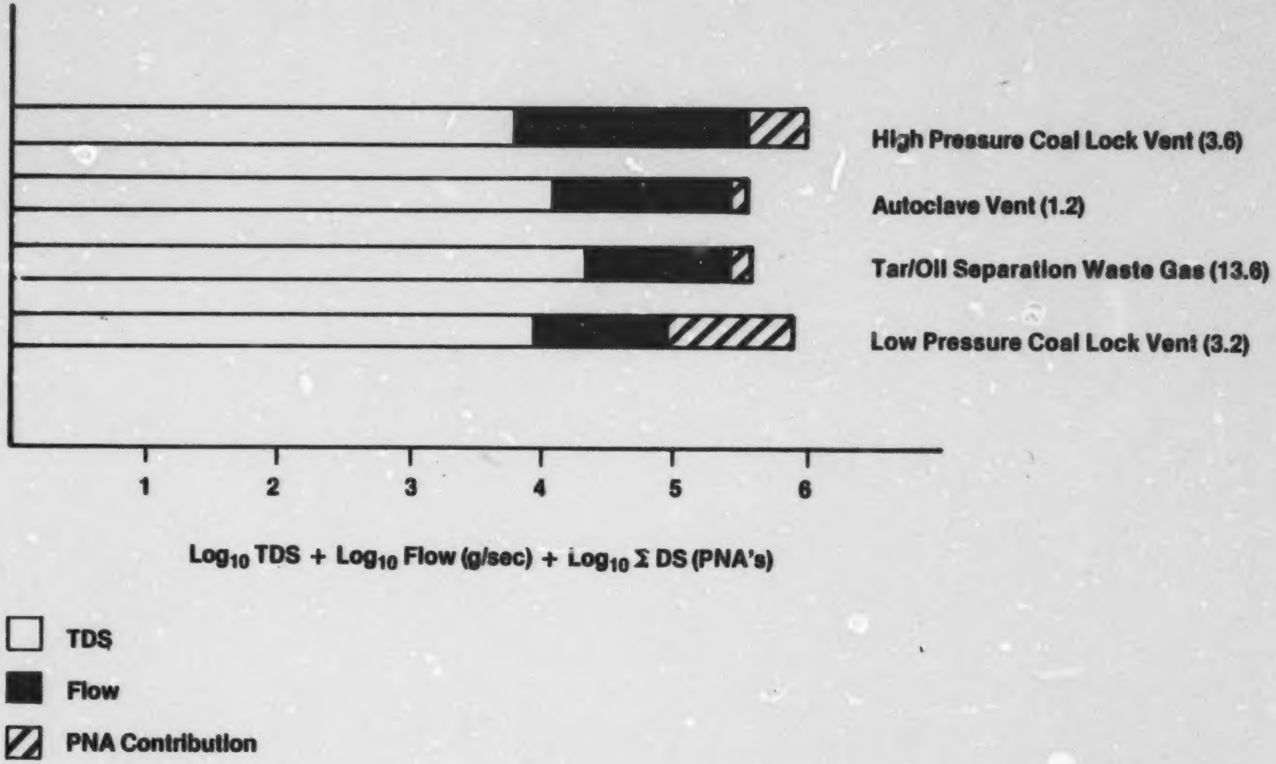


Figure 5-5. The effects of PNA contributions on the total weighted discharge severity values (health) for four gaseous discharge streams.

TABLE 5-6. KOSOVO AQUEOUS STREAM DATA

PLANT SECTION:	GAS PRODUCTION	PHENOSOLVAN	
SAMPLE POINT:	12.3 Gasification Section Wastewater	14.0 Phenolic Water	14.11 Phenosolvan Outlet Water
Flow Rate (m^3/gasifier-hr)	3.0	>13	13
Ph	8.1	9.2	9.6
Temperature (°C)	-	60	33
Solids Analysis (mg/L)			
Total Solids	10,900	2,230	1,350
Suspended Solids	8,760	150	190
Dissolved Solids	2,100	2,170	1,160
Water Quality Parameters			
COD (as mg O_2/L)	1,460	18,900	7,910
Permanganate (mg/L)	8,060	14,200	4,040
BOD_5 (as mg O_2/L)	90	9,030	2,350
TOC	-	4,970	1,470
Aqueous Composition Data (mg/L)			
Total Phenols	-	2,120	230
Volatile Phenols	0.17	-	130
Free Ammonia	Tr	3,510	Tr
Fixed Ammonia	1.9	250	205
Cyanide	0.01	<1	0.019
Nitrites	0.40	-	Tr
Nitrates	4.8	<1	11.4
Pyridines	-	140	-
Chlorides	28	-	60
Fluorides	0.91	-	Tr
Total Sulfur	-	-	84
Sulfites	Tr	-	-
Sulfates	495	-	110
Sulfides	Tr	-	-
Thiocyanates	0.26	>75	<75
Thiosulfates	Tr	-	Tr
PNA Analysis (mg/L)			
Benz(a)anthracene	-	0.92	NF
7,12-dimethylbenz(a)anthracene	-	0.23	NF
Benzo(a)fluoranthrene	-	0.68	NF
Benzo(a)pyrene	-	0.19	--
3-methylcholanthrene	-	<0.004	NF
Dibenz(a,h)anthracene	-	0.02	NF
252 Group (as BaP)	-	1.3	0.19

Tr = Trace
NF = Not Found
- = Not Analyzed

Mercury was found in the phenolic water at the Phenosolvan inlet (14.0) at a level of 0.14 mg/L. No guidelines are currently available which can be applied directly to wastewater effluents. However, an indirect comparison can be made to the MEG value for mercury (0.01 mg/L) which is defined as that threshold level at which a concern for adverse health effects begins. Another indirect comparison can be made to the mercury level of 0.2 mg/L for Extraction Procedure (EP) toxic wastes (Ref. 5-2) defined in RCRA. This guideline, which is 100 times the Federal Drinking Water Standard, is not exceeded.

Phenols and ammonia were not expected in the gasification section wastewater. It is unlikely that either compound would survive migration through the fire zone to the ash lock. These compounds also were detected in the ash lock vent gases, however, confirming their presence at the point of ash quench. It is expected that their presence may be due to the use of Fleissner condensate or phenolic water as make-up water in the ash quench process. The sulfur species in the gasification section wastewater and the phenolic water were present primarily in the form of sulfate.

The Phenosolvan section wastewater stream data presented in Table 5-6 indicate that a significant reduction in the organic pollutant load is achieved by the Phenosolvan section. As expected, the phenol level was reduced significantly (by approximately 90%) by treatment in the Phenosolvan section. It is also important to note that the concentrations of several significant PNA's were reduced to undetectable levels. The by-product phenol stream was probably the vehicle by which the PNA's in the inlet wastewater left the Phenosolvan section. The Phenosolvan Section lowers the TWDS (Health) of the phenolic wastewater from 1.12 E+07 to 1.22 E+05.

Although a significant portion of the phenolic material was removed from the Phenosolvan inlet water, a significant amount of organic matter remained in the discharge. This assertion is supported by the following data:

- TOC in outlet water - 1470 mg/L,
- Phenols in outlet water - 230 mg/L,
- Volatile phenols in outlet water - 130 mg/L.

The level of volatile phenols in the outlet water is still the dominant concern for reducing the TWDS or level of concern. Since the composition of the unextracted TOC has not yet been determined, no realistic assessment has been made of the character of the bulk of this material. However, a relatively large fraction of the inlet TOC (30%) remains in the wastewater after extraction in the laboratory with diethyl ether and methylene chloride at both pH = 1 and pH = 12.

5.3 SOLID DISCHARGES INCLUDING A COMPARISON TO GASEOUS AND AQUEOUS DISCHARGES

This section deals with solid discharges at the Kosovo Plant along with results of leaching studies on the ash. At the end of the section, there is a comparison of the 3 categories of discharges: gaseous, aqueous and solid.

5.3.1 Solid Discharges and Results of Leaching Studies

The two most significant solid discharges are the gasifier ash (12.1) and heavy tar (13.8). All comparison data from the test program along with the leaching results on the ash are listed in Appendix A.

The dry gasifier ash (12.1) is composed of a mixture of minerals and trace elements which are origin-dependent (Kosovo lignite). The results of the moisture free Ultimate Analyses show a carbon content at 1.78 weight %, oxygen of 2.3%, and hydrogen of 0.26%, with the rest of the components accounting for less than 0.2%. The ash does have a positive heating value, but it is not classified as ignitable and, therefore, would not require special handling in accordance with current applicable RCRA criteria for ignitable wastes. Quenched ash is landfilled at the Kosovo plant.

The heavy tar (13.8) is 56.0% carbon, 7.6% hydrogen, 0.87% nitrogen and 0.33% sulfur based on dry weight. It has an ash content of 6.6% and a heating value of 26.5 kJ/g. Heavy tar contains substances of relatively higher environmental concern including phenols and polynuclear aromatics (benzo(a)pyrene alone is 0.024% by weight). This material is landfilled at the Kosovo plant. Due to its heating value, this material might be used as a fuel in future U.S. plants when mixed with other by-products.

Since heavy tar (13.8) in U.S. plants will probably be recycled to the gasifier or burned as a fuel, the amount and disposition of the gasifier ash (12.1) dominates the solid discharge picture. The gasifier ash will most likely be landfilled due to the amount and nature of this discharge. Instead of concern for the solid, the leaching of substances out of the ash is of major importance. In order to determine the leaching characteristics of this material and to predict its classification under RCRA guidelines, a series of leaching studies were conducted. The results of these tests, which are reported in Appendix A, indicate that no trace elements are present in the ash leachate which would cause this material to be classified as hazardous.

5.3.2 Comparison of All Discharge Media

A direct comparison of discharge severity for all media is possible since it is a unitless value. Figure 5-6 shows the major gaseous, aqueous, and solid discharge streams from the Kosovo plant along with their corresponding TDS and TWDS values. These values use the Health-based MEG's and the common flow unit, g/sec, for all streams.

Only one stream, the quenched ash wastewater, has a TDS less than 1 E+01. The TDS for the RCRA based ash leachate is over an order of magnitude higher. This may be due to the alkaline nature of the Kosovo ash versus the acetic acid used in the RCRA leaching tests to obtain leachable trace elements.

The TDS (health) values for all other streams are significantly greater than 1 E+01, therefore, by the SAM/1A Model, there is a high degree of concern for these discharges. The TWDS (health) values range from about 1 E+04 to 1 E+07.

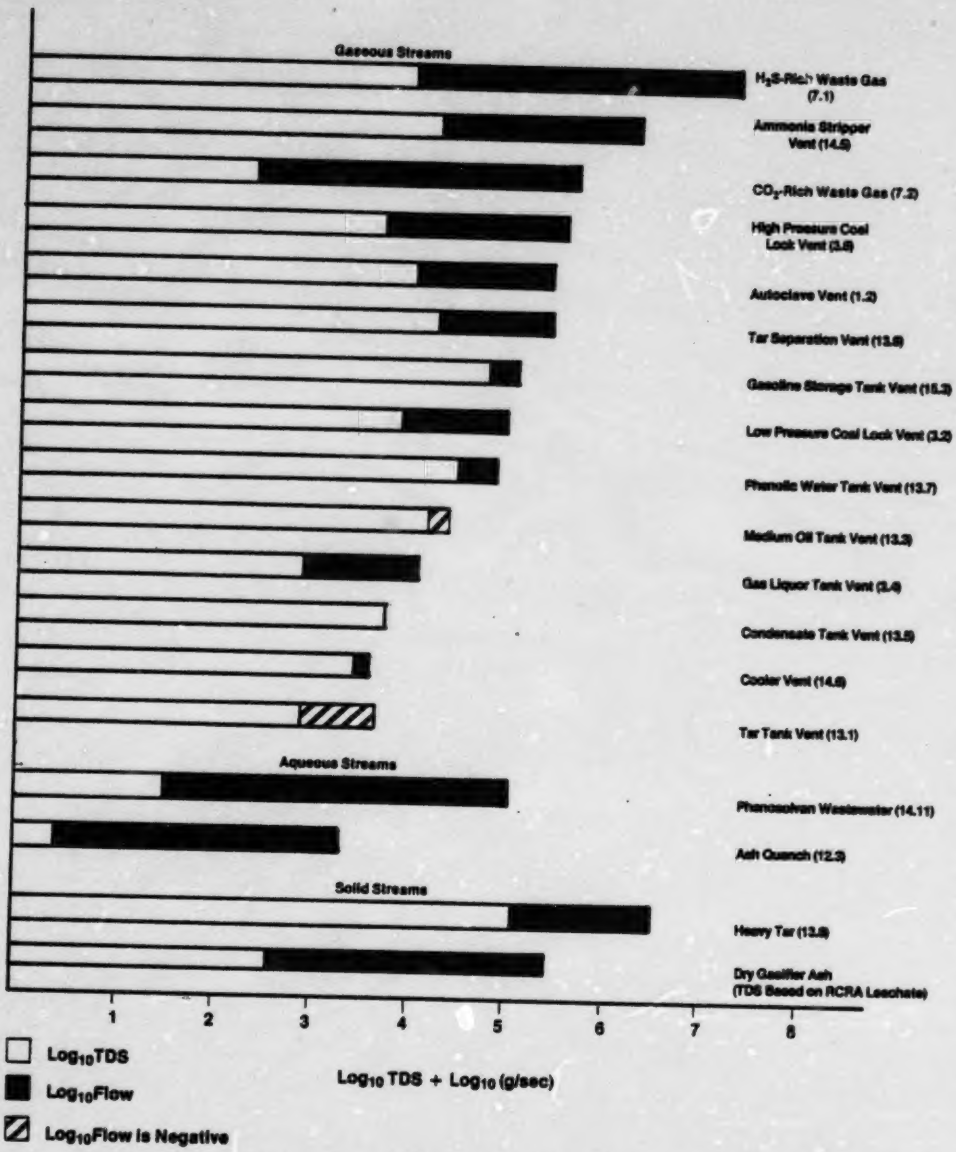


Figure 5-6. A comparison of the total weighted discharge severity values (health) for key Kosovo gaseous, aqueous and solid streams.

5.4 PRODUCT AND BY-PRODUCT STREAMS

The composition of the products and by-products impact their final uses and any environmental problems associated with those intended uses. Composition data for the lean product gas stream (7.4) and for the naphtha, medium oil and light tar by-products are presented in Appendix A.

Table 5-7 contains a summary of the compsotion data, excluding trace elements, for the crude product gas (7.3) and clean product gas (7.4) streams. The clean product gas (7.4) from the Rectisol section shows a composition of mostly H_2(60% v/v), CO (22% v/v), and CH_4(16% v/v). The sulfur species have been reduced to relatively low levels and NH_3 was not detected. By comparing the clean product gas (7.4) to the crude product gas (7.3) in Table 5-7, the efficiency of the Rectisol clean-up can be seen. Furthermore, what has been taken out of the crude gas must now exit in the Rectisol waste gas stream (7.1 and 7.2). Large amounts of H_2S exit the plant from this section.

The Ultimate Analyses data for the Lurgi by-products are listed in Table 5-8. When the heavy tar is excluded in a comparison, two trends are evident. The sulfur content decreases and the nitrogen content increases when going from the lower boiling fractions to the higher boiling fractions (naphtha → medium oil → light tar). The heavy tar was excluded due to its high water and particulate content. The ratio of N/S in heavy tar is identical to that in light tar. If the heavy tar composition was corrected for particulate content (assuming this material to be coal dust), then the trend would follow that set by the other by-products for N and S content.

Appendix A contains the trace element data for the by-products. The organic compounds would overshadow the trace elements on the basis of environmental burden if the by-products were considered discharges. However, on-site burning appears to be the preferred end use for these by-products in conceptual U.S. plants. After mixing with other fuels, most organics in the by-products will be destroyed in a high efficiency burner. However, the trace elements may continue to be of concern in the flue gas. For instance, if medium oil were burned, As could be as high as 680 ug/m^3 (25°C). The discharge severity for As in air would be 3.4 E+02.

Headspace analyses were performed on the by-products. These data appear in Appendix A. The concentrations of benzene, toluene, xylenes, and mercaptans in the headspace of the lower boiling by-products indicate that the storage tank vents were sources of environmental concern. These sources were measured in Phase II and were discussed in Section 5.1.

5.5 BIOASSAY RESULTS

Bioassay tests were run on the by-products (except crude phenol), wastewaters, gasifier ash, and leachates from the gasifier ash and heavy tar. The leachates were generated using the ASTM procedure (neutral leaching). Appendix B contains a complete report of the bioassay results.

TABLE 5-7. COMPARISON OF PRODUCT GAS COMPOSITION ENTERING AND LEAVING THE RECTISOL GAS CLEANING PLANT

Composition	Crude Product Gas 7.3	Clean Product Gas 7.4
Fixed Gases (vol %)		
H_2	38.1	60
O_2	0.36	0.44
N_2	0.64	0.38
CH_4	11.5	16
CO	15	22
CO_2	32	0.02
Sulfur Species (ppmv)		
H_2S	6000	NF
COS	97	0.17
CH_3SH	590	1.1
C_2H_5SH	200	1.0
Hydrocarbons		
Ethane (vol %)	0.47	0.15
Ethylene (vol %)	0.04	Tr
C_3 (vol %)	0.19	Tr
C_4 (vol %)	0.074	Tr
C_5 (vol %)	0.044	Tr
C_6^+ (vol %)	0.064	0.03
Benzene (ppmv)	750	-
Toluene (ppmv)	230	-
Xylene & Ethylbenzene (ppmv)	100	-
Phenols (ppmv)	Tr	Tr
Higher Aromatics (ppmv)	-	-
Nitrogen Species (ppmv)		
NH_3	3.3	Tr
HCN	320	-

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all other species.

Tr = Trace, ≃ 0.01 vol % for fixed gases and ≃ 1 ppmv for all other species.

- = No data available.

TABLE 5-8. COMPARISON OF ULTIMATE ANALYSIS DATA FOR KOSOVO BY-PRODUCT TARS, OIL AND NAPHTHA

	Heavy Tar***	Light Tar	Medium Oil	Naphtha
C	56.0	81.9	81.8	85.7
H	7.6	8.4	8.9	9.9
N	0.87	1.3	1.0	0.18
S	0.33	0.49	0.83	2.2
Ash	6.6	0.22	0.03	---
O (by difference)	28.6	7.8	8.2	2.1
Moisture	---	1.1	0.8	---
HV*	26.5	37.3	38.3	41.6
SO_2**	240	260	380	1060

*HV = Heat value expressed as KJ/g.

**Expressed as ng/J assuming 100% conversion of S to SO_2.

***Moisutre free analysis.

SO_2 Emission Limitations for Utility Steam Generators (Ref. 5-3):

Solid Fuels 86-520 ng/J (0.2 - 1.2 lb/10^6 Btu).

Liquid Fuels 340 ng/J (0.8 lb/10^6 Btu).

Table 5-9 contains a summary of the bioassay results. The following conclusions can be drawn from these results:

- the gasifier ash is not a very toxic substance and all tests including those on the ASTM leachate show little or no biological activity;
- the organic by-products (light tar, medium oil and naphtha) were the most toxic of the samples tested in the rodent tests; the tars gave a positive response to the Ames' test, which was expected from the levels of known carcinogens found in these materials; and
- the Phenosolvan unit reduced the biological activity of the wastewaters significantly.

5.6 MASS BALANCES

Mass balance calculations performed on the "best values" of the Kosovo data for the key elements carbon, nitrogen, and sulfur show that major portions of these elements are discharged in gaseous streams. The results of these calculations are shown in Figure 5-7. A detailed discussion of the methods used to obtain these balances is included in Appendix C. Also included in Appendix C are the mass balance calculations and results around each section of the Kosovo gasification plant.

In figure 5-7 the dried coal and the oxygen streams are assigned a value of 100% of the incoming N, S, and C to the gasification plant since they are the only sources of these elements. The rest of Figure 5-7 shows the amount of each of these elements in key Kosovo solid, liquid and gaseous streams expressed as a percentage of these elements entering the gasifier. This figure shows that the majority of the carbon entering the system with the dried coal stream leaves in gaseous streams. The three major gaseous streams accounting for the carbon are the clean product gas (7.4), H_2S-rich waste gas (7.1) to flare, and CO_2-rich waste gas (7.2). Relatively little of the inlet carbon ends up in the gasifier ash (0.7%), aqueous wastewaters (0.3%) and the remaining gaseous discharge streams. The percentage of the carbon in the coal which is accounted for in the various product and waste streams is 92%.

The major stream accounting for most of the sulfur leaving the plant is the H_2S-rich waste gas (7.1) which is part of the flare feed system in the Kosovo plant. Much of the remaining sulfur exiting the plant appears in the by-products - naphtha (2.0%), medium oil (1.5%), and light tar (1.4%) - and the ammonia stripper vent (4.8%). Some of the sulfur is discharged in the ash (1.7%), heavy tar (0.2%), and the wastewaters (1.1%). The three major sulfur species which exit the plant are H_2S, CH_3SH and C_2H_5SH. The percentage of the sulfur in the coal accounted for in the product and waste streams is 180%. The poor accountability of this balance is probably due to variations in the input coal sulfur content (see Section 5.7) and variations in flow measurements.

TABLE 5-9. A SUMMARY OF THE BIOASSAY RESULTS

Sample Number	Description	Ames*	In Vitro Cytoxicity ** EC_{50}†	Rodent†† Test/ Control
2468	Ash	Negative	>1000	1/2
1152A	Naphtha	Negative	0.68	7/2
2471	Medium Oil	Negative	0.11	10/2
2472	Tar	Positive	0.03	7/2
2473	Heavy Tar	Positive	0.07	3/1
2987	Phenolic Water	Positive	37	1/2
2988	Phenosolvan Waste-Water (Outlet)	Negative	98	0/2
2468L	ASTM Ash Leachate	Negative	>600	1/0
2473L	ASTM Heavy Tar Leachate	Negative	120	3/0

* Highest concentration tested varied depending on sample toxicity. See Appendix B.

**All samples tested in CHO assay except the ash sample which was tested in the RAM assay.

†EC_{50}'s given in µL/mL or µg/mL (EC= Effective Concentration).

††Number of dead mice in test group over control group. Ten animals were used in each group. See details in Appendix B.

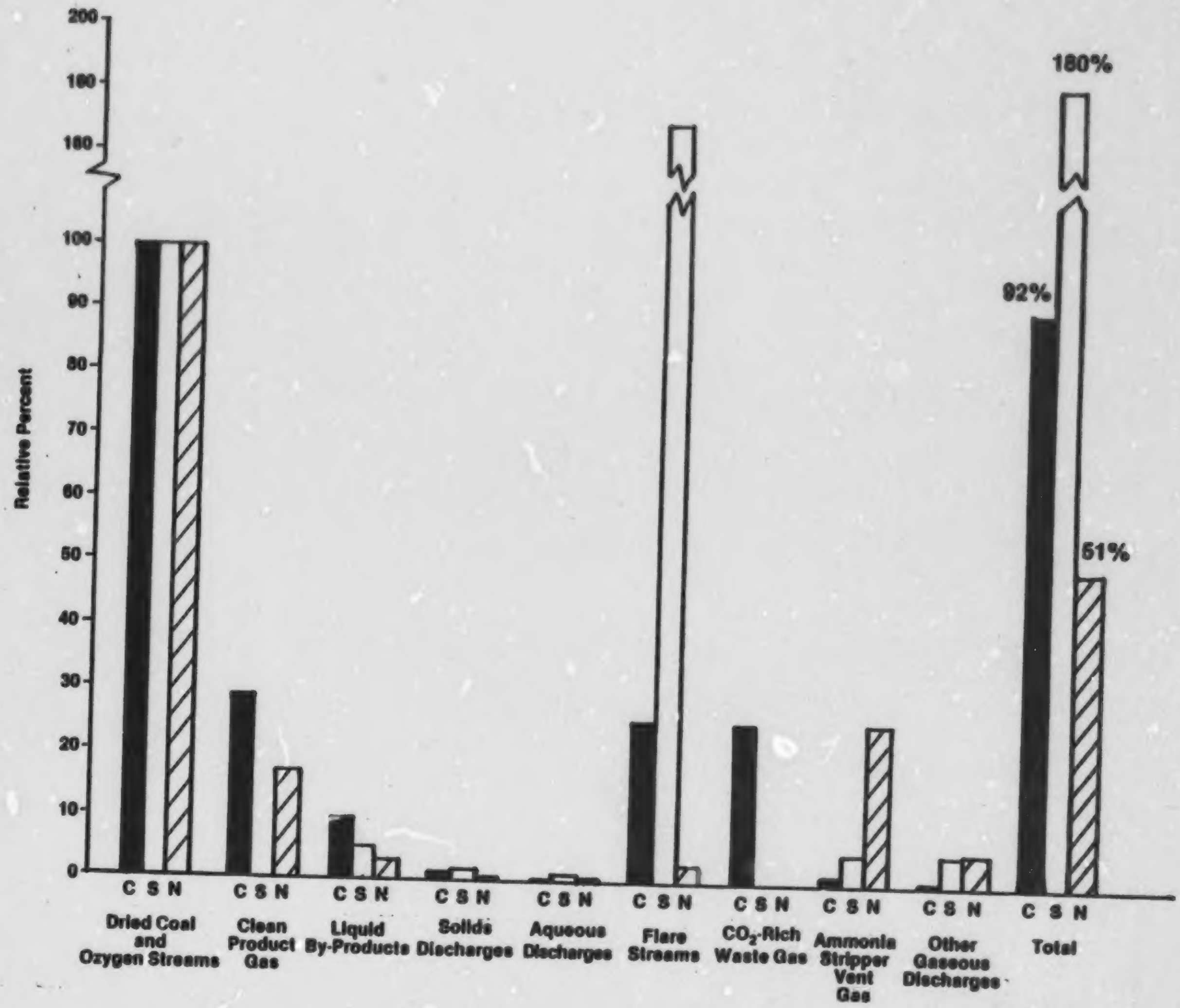


Figure 5-7. Mass balances for carbon, sulfur and nitrogen in Kosovo process and discharge streams.

Nitrogen entering in the dried coal feed is converted primarily to ammonia, hydrogen cyanide and pyridine-like compounds in the liquid by-products. Nitrogen entering with the oxygen feed to the gasifiers is in the form of molecular nitrogen. The major stream accounting for almost half of the exiting nitrogen is the ammonia stripper vent (14.5). In analyzing the gas phase results, it was difficult to discriminate between molecular nitrogen acutally present in the gas stream and nitrogen due to sample contamination with air. Due to this problem and the variability of the nitrogen content in the feed coal, the accountability was low. The product and waste streams accounted for 51% of the nitrogen entering with the coal and oxygen feed streams to the gasifiers.

Appendix C also contains a balance of trace elements around the Kosovo gasification facility. A trace element balance was not the intent of this study; however, based on the limited data available, an understanding of the fate of trace elements was obtained.

As expected, most of the trace elements that entered the plant in the form of coal left the plant in the form of gasifier ash. Results from trace element analyses of streams 7.1, 7.2, and 7.4 showed that only a very small amount of the most volatile elements were discharged in the Rectisol gaseous streams and/or product gas. Most of the mercury stayed in the aqueous phase streams and was discharged from the plant in the Phenosolvan section.

5.7 ADDITIONAL COMMENTS AND SUMMARY OF FINDINGS

Comments on how the data was interpreted and what impacts new data will have on the results are included in this section. The major findings are summarized in this section.

5.7.1 Variation of Feed Coal

One source of variations in the measured composition of the products and waste streams is the composition of the feed coal, which was not constant from day to day. Figure 5-8 illustrates the day-to-day variation in the composition of the coal. Within a two week period the sulfur content of the coal varied from approximately 1% to 1.8%. The impacts on the mass balance calculations and stream composition are obvious since the lignite is the only source of sulfur. Similar variations could also have affected the nitrogen mass balances, since carbon is the major component in the coal, the relative variations in composition should impact the carbon mass balance calculations to a much lesser degree.

5.7.2 Comments on SAM/1A

The SAM/1A treatment of the data in this Source Test and Evaluation Report (STER) has been used on a compound specific basis. Only where compounds or groups of compounds (e.g., total phenols) have been identified and quantified have their values been used in the calculation of the TDS and TWDS of the discharges. If this had been a screening test, the "worst case"

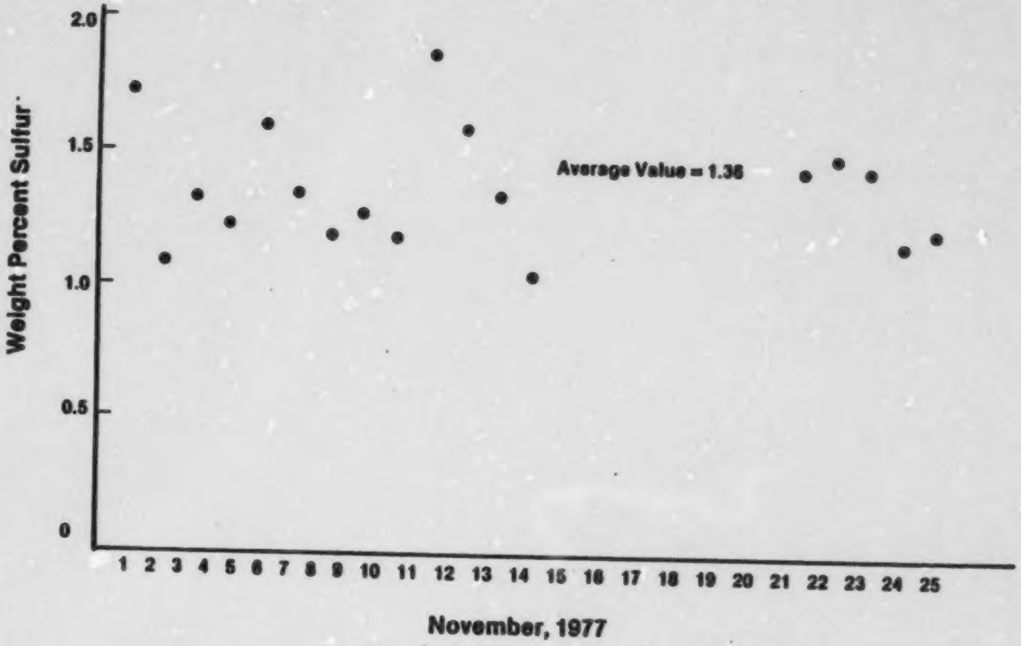


Figure 5-8. Daily variation in the sulfur content of Kosovo lignite.

compound in a MEG category would have been used for any unknowns. For example, if the tars and oils from a particulate catch had been separated into a PNA fraction, this total fraction would have been assumed to be benzo(a)pyrene This was not done in this STER.

The SAM/1A was also used to prioritize the analytical schemes and thus lower the source assessment cost. Obviously, all species cannot be identified in all streams. However, if the major components are quantified and the TDS of the stream is calculated, then the species which can impact the TDS have been drastically reduced. For example, the light tar was analyzed for the most hazardous compounds which could be produced by a gasifier, (see the PNA's in Appendix A). Knowing the TDS calculated from these PNA's, the number of compounds which could be in the rest of the tar and still impact the TDS was small. Once the major phenols had been quantified, the number of compounds which could make up the rest of the tar and which could increase the TDS even by 10% was less than twenty.

5.7.3 Impact of New Data

This study provides a meaningful measure of environmental concerns within Lurgi-type technology. However, with any study of this magnitude, cost must be weighed against the accuracy of the data. New data which is more accurate than that contained herein may cause the TDS (Total Discharge Severity) of a stream to go up or down slightly. Drastic changes, however, are not expected. When the TDS values are in the range of 10^3 to 10^5 as in most of the gaseous discharge streams, more accurate data, which changes the concentration or flow data by even as large a factor as 2, will not greatly impact these orders of magnitude of concern.

As stated earlier, only identified and quantified species were used to calculate TDS values. Quantification of other organic or inorganic species will only increase the TDS levels. For example, when the polynuclear aromatic hydrocarbon content of medium oil and light tar was used to estimate the TWDS of the low pressure coal lock vent (3.2), the TWDS increased by almost a factor of ten.

5.7.4 Summary of Findings

The Kosovo Phase II data has corroborated the indications from the Phase I test results and has also added new information about the aqueous and solid discharges from the Kosovo plant. It has also provided significant information about trace pollutants, both organic and inorganic. The following are some of the more salient findings:

- All discharge streams - gaseous, aqueous and solid, have a significant potential for polluting the environment.
- Highest priority streams in each medium are:
  gaseous - H_2S-rich waste gas,
  aqueous - phenolic wastewater, and
  solid - heavy tar.

However, most of the major discharge streams sampled were found to contain pollutants which may require emission controls.

- PNA's make a significant contribution to the severity of tar bearing streams, such as:
  - LP coal lock vent, and
  - heavy tar.

  The severity of the LP coal lock vent discharge is increased significantly by the assumed contribution of PNA's in the tar aerosol.
- Benzo(a)pyrene and 7,12-Dimethylbenz(a)anthracene are the two most significant pollutants in Kosovo tar.
- Trace elements were found to be less significant than trace organics as pollutants.
- Mercury was found in phenolic water at significant levels. This accounts for most of the mercury entering the system with the coal.
- Ash leaching problems appear to be of low concern. Concentrations of all trace elements were at least an order of magnitude lower in the RCRA leaching method than the levels specified in the EPA toxicity test.
- Residual sulfur species and hydrocarbons in the CO_2-rich waste gas will cause control problems due to the energy poor nature of this stream.
- Even after Phenosolvan treatment, the wastewater has high residual organic material and solids which must be addressed in controlling discharges.
- The high TWDS and high heating values of the heavy tar will probably require that this solid waste material be disposed of in a manner diffrent from landfilling as done at Kosovo.
- No significant concentrations of trace elements were found in the product gas or Rectisol gas streams; most of the trace elements volatilized in the gasifier end up in the heavy tar, liquid by-products, and the Phenosolvan wastewater.
- The Rectisol process is effective in "cleaning up" the product gas. Its use in the U.S. will depend on the availability of satisfactory control technology for the H_2S-rich and CO_2-rich waste gases produced.

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APPENDIX A
COMPILATION OF RESULTS

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KOSOVO SOURCE TEST AND EVALUATION REPORT (PHASES I AND II) DATA APPENDIX

A1.0 INTRODUCTION

This Appendix presents a compilation of the currently available data obtained during Phases I and II of the Kosovo test program. For each sample point, overall characteristic values are given for all species analyzed. Where multiple data analyses were available, a range of values is included. This range defines the normal range of the component as best determined from the process, design, and experimental data available. In arriving at the overall values, plant conditions, sampling methods, and sampling conditions were all considered. For sections of the plant where enough data was available, mass balance calculations were used to ascertain the validity of the data. These mass balance calculations are discussed in Appendix C.

The results of Phase I and Phase II gaseous stream analyses are presented in Section A2.0. Data are presented for 27 direct discharge sources, five flare feed streams, and three process streams. These streams were surveyed during Phase I. Based on the Phase I results, nine direct discharge, five flare feed, and three process streams were selected for a more thorough analysis in Phase II of the test program.

In compiling the gaseous stream data to arrive at overall characteristic values, preference was given to data obtained during the more complete Phase II test program. In Phase II, two methods were used to analyze for H_2S in gaseous streams. These were the wet impinger and gas chromatograph (GC) methods. For streams with low (<10 wt%) moisture content, both methods gave similar results. However, for high moisture content streams (>10 wt%), the results obtained from the two methods varied considerably for reasons which are discussed in the sampling and analysis section (Section 4.0) of this report.

The results from particulate sampling/analyses are presented in Section A3.0. Eight gaseous streams were sampled for entrained particulates. Whenever possible, each particulate catch was separated into three fractions: filterable solids, condensed organics (extractable), and dissolved solids.

Analyses were performed on samples from five aqueous streams during Phases I and II of the test program. A compilation of the results is given in Section A4.0. For trace elemental analyses, two methods, Atomic Absorption Spectrophotometry (AA) and Spark-Source Mass Spectrometry (SSMS) were used. Since the accuracy obtained by these methods differs greatly, results are reported separately. A more complete discussion of these methods is given in the section discussing analytical methods (Section 4.0).

Section A5.0 presents a compilation of data obtained from six solid phase streams. For the gasifier ash, samples of both the hot, dry ash and the quenched, wet ash were analyzed. RCRA (acid) and ASTM (neutral) leachate tests were performed on the dry gasifier ash. The results are shown in Section A6.0.

Headspace analyses were performed for some by-products and for heavy tar. The by-products analyzed were naphtha, medium oil, light tar, and crude phenol. The results are given in Section A7.0.

Light tar, medium oil, and naphtha, three of the by-products generated at the Kosova plant, were also analyzed. A compilation of these results is shown in Section A8.0.

The compilations in Sections A4.0 through A8.0 are not separated by the phase in which the analyses were performed as in Sections A2.0 and A3.0. Instead, one overall value and a range are shown. There were not enough data in these sections to justify identifying the phases in which the sampling and analyses were performed.

A2.0. COMPILATION OF DATA FOR GASEOUS STREAMS

TABLE A.2-1. TEST DATA FOR GAS PHASE SAMPLE POINT 1.2, FLEISSNER AUTOCLAVE VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)			57.8		57.8	
Temperature (°C)			–		–	
Molecular Wt. of Dry Gas			33.4		33.4	
Moisture Content (wt %)			76		76	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NO PHASE I DATA		Tr	NF-Tr	Tr	NF-Tr
O_2			14	20-21	14	10-21
N_2			56	30-79	56	30-79
CH_4			Tr		Tr	
CO			Tr		Tr	
CO_2			29	26-48	29	26-48
Sulfur Species (ppmv)						
H_2S			2400	740-3600	2400	740-360
COS			30		30	
CH_3SH			3400	2700-4200	3400	2700-4200
C_2H_5SH			2100	1700-2500	2100	1700-2500
C_1-C_6+ Hydrocarbons (vol %)						
Ethane			Tr		Tr	
Ethylene			NF		NF	
C_3			0.03	0.01-0.04	0.03	0.01-0.04
C_4			0.03	0.001-0.03	0.03	0.001-0.03
C_5			NF		NF	
C_6+			0.01	0.01-0.39	0.01	0.01-0.39
Aromatic Species (ppmv)						
Benzene			17	4.5-17	17	4.5-17
Toluene			6.8	2.5-6.8	6.8	2.5-6.8
Xylene + Ethylbenzene			4.2	4.2-22	4.2	4.2-22
Phenols			–		–	
Higher Aromatics			–		–	
Nitrogen Species (ppmv)						
NH_3			–		–	
HCN			–		–	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-2. TEST DATA FOR GAS PHASE SAMPLE POINT 2.2, DEDUSTING CYCLONE VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m³ at 25°C/gasifier-hr)	4600	4600-15500	7200		7200	4600-15500
Temperature (°C)	10	10-14	27		27	10-27
Molecular Wt. of Dry Gas	28.6		–		28.6	
Moisture Content (wt %)	2.4	2.1-2.5	3.0		3.0	2.1-3.0
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF	NF-0.8	–		NF	NF-0.8
O_2	20.8	19-21	–		20.8	19-21
N_2	78.2	78-80	–		78.2	78-79
CH_4	NF	NF-Tr	–		NF	NF-Tr
CO	NF	NF-Tr	–		NF	NF-Tr
CO_2	NF		–		NF	
Sulfur Species (ppmv)						
H_2S	NF		–		NF	
COS	NF		Tr		NF	NF-Tr
CH_3SH	NF		NF		NF	
C_2H_5SH	NF		NF		NF	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	NF	NF-Tr	–		NF	NF-Tr
Ethylene	–		–		–	
C_3	NF	NF-Tr	–		NF	NF-Tr
C_4	NF	NF-Tr	–		NF	NF-Tr
C_5	NF	NF-Tr	–		NF	NF-Tr
C_6+	NF	NF-Tr	–		NF	NF-Tr
Aromatic Species (ppmv)						
Benzene	–		–		–	
Toluene	–		–		–	
Xylene + Ethylbenzene	–		–		–	
Phenols	Tr		–		Tr	
Higher Aromatics	–		–		–	
Nitrogen Species (ppmv)						
NH_3	NF	NF-30	–		NF	NF-30
HCN	NF		–		NF	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-3. TEST DATA FOR GAS PHASE SAMPLE POINT 3.1, COAL LOCK BUCKET VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m³ at 25°C/gasifier-hr)	-				-	
Temperature (°C)	-				-	
Molecular Wt. of Dry Gas	-				-	
Moisture Content (wt %)	-				-	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	1.8		NO PHASE II DATA		1.8	
O_2	18				18	
N_2	77				77	
CH_4	-				-	
CO	0.6				0.6	
CO_2	-				-	
Acid Gases (vol %)	2.6				2.6	
Saturated Hydrocarbons (vol %)	0.6				0.6	
Unsaturated Hydrocarbons (vol %)	NF				NF	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

*Values are best values from available data

TABLE A.2-4. TEST DATA FOR GAS PHASE SAMPLE POINT 3.2, LOW PRESSURE COAL LOCK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–		21.0		21.0	
Temperature (°C)	56	46-65	–		56	
Molecular Wt. of Dry Gas	24.9		23.3		23.5	
Moisture Content (wt %)	44	8.1-44	44	30-44	44	8.1-44
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	34	33-44	33	22-37	37	22-44
O_2	0.7	0.7-1.5	0.27	0.26-4.3	0.27	0.26-4.3
N_2	2.5	2.2-2.6	0.18	0.14-18	0.18	0.14-18
CH_4	9.4	9.3-9.4	8.6	2.8-8.6	8.6	2.8-9.4
CO	9.3	9.2-11	14.6	2.4-15	14.6	2.4-15
CO_2	42	29-42	36.5	36-52	36.5	29-52
Sulfur Species (ppmv)						
H_2S	3800	2000-9800	13000	10000-33000	13000	2000-33000
COS	170		110	90-130	110	90-170
CH_3SH	260		420	400-2500	420	260-2500
C_2H_5SH	84		220	120-870	220	84-870
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	0.72	0.72-0.84	0.22	Tr-0.72	0.22	Tr-0.72
Ethylene			Tr	NF-Tr	Tr	NF-Tr
C_3	0.29	0.29-0.38	0.14	0.14-0.64	0.14	0.14-0.64
C_4	0.09	0.09-0.16	0.05	0.05-0.37	0.05	0.05-0.37
C_5	0.05	Tr-0.05	Tr	Tr-0.17	Tr	Tr-0.17
C_6+	0.03	Tr-0.03	0.12	0.08-0.19	0.12	Tr-0.19
Aromatic Species (ppmv)						
Benzene	–		760	750-760	760	750-760
Toluene	–		220	190-240	220	190-240
Xylene + Ethylbenzene	–		75	70-85	75	70-85
Phenols	Tr	Tr-5.4	5.7		5.7	Tr-5.7
Higher Aromatics	–		–		–	
Nitrogen Species (ppmv)						
NH_3	7000	180-7000	2400	1000-3700	2400	180-7000
HCN	48		600	48-680	600	48-680

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-5. ATOMIC ABSORPTION DATA FOR THE LOW PRESSURE COAL LOCK VENT (3.2)

Component (μg/m³)	Phase II Value
As	1700
Be	4.0
Cd	27
Co	4.9
Cr	270
Cu	180
Hg	53
Mo	45
Ni	120
Pb	72
Sb	NF
Se	NQ
Sr	610
Tl	NF
V	9.0
Zn	1600

NF = Not found
NQ = Present, but not quantifiable

TABLE A.2-6. TEST DATA FOR GAS PHASE SAMPLE POINT 3.3, GASIFIER START-UP VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)			-		-	
Temperature (°C)			-		-	
Molecular Wt. of Dry Gas			33.1		33.1	
Moisture Content (wt %)			70		70	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NO PHASE I DATA		0.09	0.09-0.27	0.09	0.09-0.27
O_2			4.5	4.4-18	4.5	4.4-18
N_2			42	42-67	42	42-67
CH_4			1.6	0.8-1.6	1.6	0.8-1.6
CO			14	3.7-14	14	3.7-14
CO_2			34	10-34	34	10-34
Sulfur Species (ppmv)						
H_2S			6300		6300	
COS			110	40-120	110	40-120
CH_3SH			490	90-520	490	90-520
C_2H_5SH			240	30-250	240	30-250
C_1-C_6+ Hydrocarbons (vol %)						
Ethane			0.15	0.07-0.15	0.15	0.07-0.15
Ethylene			0.05	0.004-0.05	0.05	0.004-0.05
C_3			0.08	0.03-0.08	0.08	0.03-0.08
C_4			0.03	Tr-0.04	0.03	Tr-0.04
C_5			0.007	Tr-0.009	0.007	Tr-0.009
C_6+			0.09	0.03-0.09	0.09	0.03-0.09
Aromatic Species (ppmv)						
Benzene			90	10-90	90	10-90
Toluene			10	Tr-10	10	Tr-10
Xylene + Ethylbenzene			Tr	Tr-10	Tr	Tr-10
Phenols			630		630	
Higher Aromatics						
Nitrogen Species (ppmv)						
NH_3			11000		11000	
HCN			2900		2900	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

*Values are best values from available data

TABLE A.2-7. TEST DATA FOR GAS PHASE SAMPLE POINT 3.4, GAS LIQUOR TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	44				44	
Temperature (°C)	60				60	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	12		NO PHASE II DATA		12	
O_2	14				14	
N_2	56				56	
CH_4	–				–	
CO	2.6				2.6	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	1450	1400–1600			1450	1400–1600
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1–C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	Tr	Tr–9.5			Tr	Tr–9.5
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	690	99–690			690	99–690
HCN	–				–	
Acid Gases (vol %)	11	10–13			10	10–13
Saturated Hydrocarbons (vol %)	3.0				3.0	
Unsaturated Hydrocarbons (vol %)	0.5	0.4–0.6			0.5	0.4–0.6

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data.

TABLE A.2-8. TEST DATA FOR GAS PHASE SAMPLE POINT 3.5, ASH LOCK CYCLONE VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	7.1		32.8		32.8	7.1-32.8
Temperature (°C)	98	90-98	-		98	90-98
Molecular Wt. of Dry Gas	31.3		-		31.3	
Moisture Content (wt %)	85	81-97	-		85	81-97
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II COMPOSITION DATA		NF	
O_2	48				48	
N_2	35				35	
CH_4	Tr				Tr	
CO	NF				NF	
CO_2	14				14	
Sulfur Species (ppmv)						
H_2S	82	NF-82			82	NF-82
COS	NF				NF	
CH_3SH	NF				NF	
C_2H_5SH	NF				NF	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	Tr				Tr	
Ethylene						
C_3	Tr				Tr	
C_4	Tr				Tr	
C_5	-				-	
C_6+	NF	NF-Tr			NF	NF-Tr
Aromatic Species (ppmv)						
Benzene	-				-	
Toluene	-				-	
Xylene + Ethylbenzene	-				-	
Phenols	Tr	NF-16			Tr	NF-16
Higher Aromatics	-				-	
Nitrogen Species (ppmv)						
NH_3	340	130-340			340	130-340
HCN	54				54	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-9. TEST DATA FOR GAS PHASE SAMPLE POINT 3.6, HIGH PRESSURE COAL LOCK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	440		230		230	230-440
Temperature (°C)	54	54-60	-		54	54-60
Molecular Wt. of Dry Gas	24.6		24.2		24.9	
Moisture Content (wt %)	11	10-11	-		11	10-11
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	32	23-37	-		32	23-37
O_2	0.23	0.23-1.2	0.24	0.22-0.26	0.24	0.22-0.26
N_2	6.1	6.0-7.3	0.14	0.12-0.16	0.14	0.12-0.16
CH_4	11	9.9-11.0	10.5	10.0-10.7	10.5	9.9-11
CO	13	12-14	12	11-12	12	11.9-14
CO_2	37	36-38	42	37-48	42	36-48
Sulfur Species (ppmv)						
H_2S	2400	1500-3200	3500	3200-3700	3500	1500-3700
COS	290		120	95-140	120	95-290
CH_3SH	500		460	410-510	460	410-510
C_2H_5SH	80		210	190-240	210	80-240
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	0.71	0.63-0.71	0.42	0.34-0.50	0.42	0.34-0.50
Ethylene	-		Tr		Tr	
C_3	0.21	0.17-0.21	0.25	0.19-0.30	0.25	0.17-0.30
C_4	0.02	0.02-0.19	0.11	0.07-0.14	0.11	0.02-0.19
C_5	0.02	0.02-0.12	0.01	0.006-0.013	0.01	0.006-0.12
C_6+	0.05		0.08	0.06-0.09	0.08	0.05-0.09
Aromatic Species (ppmv)						
Benzene	-		550	510-580	550	510-580
Toluene	-		100	70-130	100	70-130
Xylene + Ethylbenzene	-		38	25-50	38	25-50
Phenols	2.5	1.1-2.5	-		2.5	1.1-2.5
Higher Aromatics	-		-		-	
Nitrogen Species (ppmv)						
NH_3	NF	NF-130	-		NF	NF-130
HCN	170		-		170	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-10. TEST DATA FOR GAS PHASE SAMPLE POINT 7.1, H_2S-RICH WASTE GAS

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	3730		3600		3600	3600-3730
Temperature (°C)	12		-		12	
Molecular Wt. of Dry Gas	41.2		43.0		43.0	
Moisture Content (wt %)	-		3.9		3.9	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	0.07	0.02-0.07	0.11		0.11	0.02-0.11
O_2	0.51	0.23-0.51	Tr	Tr-0.13	Tr	Tr-0.51
N_2	1.4	0.59-1.4	Tr	Tr-3.2	Tr	Tr-3.2
CH_4	4.2	4.1-4.4	4.3	4.2-4.7	4.3	4.1-4.7
CO	2.6	1.6-3.0	1.1	1.1-3.5	1.1	1.1-3.5
CO_2	86	86-92	88	85-88	88	85-92
Sulfur Species (ppmv)						
H_2S	23000	16000-27000	45400	41000-50000	45400	16000-50000
COS	<540		420	360-520	420	360-540
CH_3SH	4100	3400-4800	2100	1900-2300	2100	1900-4800
C_2H_5SH	710		780	670-850	780	670-850
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	0.34	0.34-1.5	0.82	0.80-0.97	0.82	0.34-0.97
Ethylene			Tr		Tr	
C_3	0.22	0.22-1.1	0.63	0.60-0.66	0.63	0.22-1.1
C_4	0.14	0.14-0.58	0.32	0.30-0.44	0.32	0.14-0.58
C_5	0.06	0.06-0.21	0.04	0.03-0.08	0.04	0.03-0.21
C_6+	0.01	0.01-0.12	0.21	0.12-0.22	0.21	0.01-0.22
Aromatic Species (ppmv)						
Benzene	-		110	40-110	110	40-110
Toluene	-		8	4-8	8	4-8
Xylene + Ethylbenzene	-		NF		NF	
Phenols	Tr	NF-Tr	-		Tr	NF-Tr
Higher Aromatics	-		-		-	
Nitrogen Species (ppmv)						
NH_3	2200	NF-2200	-		2200	NF-2200
HCN	83		200		200	83-200

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-11. ATOMIC ABSORPTION DATA FOR THE H_2S-RICH WASTE GAS (7.1)

Component (μg/m³)	Phase II Value
Fe (as $Fe(CO)_5$)	73
Ni (as $Ni(CO)_4$)	18
Mn (as $Mn(CO)_5$)	21

TABLE A.2-12. TEST DATA FOR GAS PHASE SAMPLE POINT 7.2, CO_2-RICH WASTE GAS

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	5100	1200-5100	3600		3600	1200-5100
Temperature (°C)	19		-		19	
Molecular Wt. of Dry Gas	41.9		23.3		42.2	
Moisture Content (wt %)	-		5.1		5.1	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	0.8	NF-0.8	Tr		Tr	NF-0.8
O_2	Tr	Tr-0.62	Tr	Tr-1.8	Tr	Tr-1.8
N_2	0.32	0.32-3.7	Tr	Tr-48	Tr	Tr-48
CH_4	0.94	0.94-1.8	1.2	0.6-1.2	1.2	0.6-1.8
CO	NF		Tr		Tr	NF-Tr
CO_2	94	91-95	51	47-54	94	91-95
Sulfur Species (ppmv)						
H_2S	39	39-90	23	20-25	39	20-90
COS	Tr		62	59-62	62	Tr-62
CH_3SH	8.2		8.5	8.2-9.7	8.5	8.2-9.7
C_2H_5SH	3.4		4.7	3.5-6.1	4.4	3.4-6.1
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	0.29	0.29-2.2	1.6	0.5-1.6	1.6	0.29-1.6
Ethylene			Tr		Tr	
C_3	0.26	0.20-0.55	0.28	0.17-0.29	0.28	0.17-0.55
C_4	Tr	NF-0.23	Tr		Tr	NF-0.23
C_5	Tr	NF-0.17	Tr		Tr	NF-0.17
C_6+	NF		-		NF	
Aromatic Species (ppmv)						
Benzene	-		1.0		1.0	
Toluene	-		Tr		Tr	
Xylene + Ethylbenzene	-		Tr		Tr	
Phenols	NF	NF-Tr	-		NF	NF-Tr
Higher Aromatics	-		-		-	
Nitrogen Species (ppmv)						
NH_3	4.6	NF-4.6	-		4.6	NF-4.6
HCN	13		-		13	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-13. ATOMIC ABSORPTION DATA FOR THE CO_2-RICH WASTE GAS (7.2)

Component (µg/m³)	Phase II Value
Fe (as $Fe(CO)_5$)	320
Ni (as $Ni(CO)_4$)	7.4
Mn (as $Mn(CO)_5$)	7.3

TABLE A.2-14. TEST DATA FOR GAS PHASE SAMPLE POINT 7.3, CRUDE PRODUCT GAS

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	-		-		-	
Temperature (°C)	20		22.3		22.3	20-22.3
Molecular Wt. of Dry Gas	22.5		21.3		21.9	
Moisture Content (wt %)	-		2.5		2.5	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	36	36-45	40	36-46	38.1	36-46
O_2	0.55	0.20-2.6	0.34	0.09-0.48	0.36	0.09-2.6
N_2	1.6	0.9-1.6	0.52	0.04-1.15	0.64	0.04-1.6
CH_4	13	8.9-13	11	9.5-14.5	11.5	8.9-14.5
CO	14	9.6-14	15	13-17	15	9.6-17
CO_2	33	21-36	31	23-40	32	21-40
Sulfur Species (ppmv)						
H_2S	4400	4400-7800	5600	4900-6700	6000	4400-7800
COS	74		97	63-120	97	63-120
CH_3SH	540		590	460-700	590	460-700
C_2H_5SH	98		200	140-270	200	98-270
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	0.65	0.65-1.1	0.44	Tr-0.76	0.47	Tr-0.76
Ethylene			0.04	Tr-0.11	0.04	Tr-0.11
C_3	0.35	0.35-0.40	0.16	0.07-0.21	0.19	0.07-0.40
C_4	0.15	0.15-0.24	0.063	0.02-0.13	0.074	0.02-0.24
C_5	0.04	0.01-0.04	0.044	0.02-0.06	0.044	0.01-0.06
C_6+	-		0.064	0.02-0.20	0.064	0.02-0.20
Aromatic Species (ppmv)						
Benzene	-		750	660-840	750	660-840
Toluene	-		230	200-260	230	200-260
Xylene + Ethylbenzene	-		100	16-110	100	16-110
Phenols	Tr		-		Tr	
Higher Aromatics	-		-		-	
Nitrogen Species (ppmv)						
NH_3	3.3	NF-3.3	-		3.3	NF-3.3
HCN	60		320		320	60-320

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-15. ATOMIC ABSORPTION DATA FOR THE CRUDE PRODUCT GAS (7.3)

Component ($\mu g/m^3$)	Phase II Value
As	0.43
Be	0.13
Cd	0.48
Co	NF
Cr	2.5
Cu	4.3
Hg	NF
Mo	NF
Ni	4.8
Pb	1.0
Sb	NF
Se	NQ
Sr	5.6
Tl	NF
V	NF
Zn	30

NF = Not found
NQ = Present, but not quantifiable

TABLE A.2-16. TEST DATA FOR GAS PHASE SAMPLE POINT 7.4, CLEAN PRODUCT GAS

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–		–		–	
Temperature (°C)	–		–		–	
Molecular Wt. of Dry Gas	10.2		10.2		10.3	
Moisture Content (wt %)	–		4.1		4.1	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	62	60–67	60	59–62	60	59–67
O_2	0.96	0.1–1.7	0.44	0.42–0.46	0.44	0.1–1.7
N_2	4.8	0.5–6.8	0.38	0.32–0.43	0.38	0.32–6.8
CH_4	14	12–18	16	15.9–16.1	16	12–18
CO	17	13–17.5	22	20.7–23	22	13–23
CO_2	0.23	NF–2.4	0.02	0.004–0.02	0.02	NF–2.4
Sulfur Species (ppmv)						
H_2S	NF		–		NF	
COS	NF		0.17	0.1–0.2	0.17	NF–0.2
CH_3SH	Tr		1.1	0.7–1.9	1.1	Tr–1.9
C_2H_5SH	Tr		1.0	0.6–1.7	1.0	Tr–1.7
C_1–C_6+ Hydrocarbons (vol %)						
Ethane	0.49	Tr–0.79	0.15	0.12–0.18	0.15	Tr–0.18
Ethylene			Tr		Tr	
C_3	Tr	Tr–0.09	Tr		Tr	Tr–0.09
C_4	Tr	NF–Tr	–		Tr	NF–Tr
C_5	Tr	NF–Tr	–		Tr	NF–Tr
C_6+	0.03	NF–0.03	–		0.03	NF–0.03
Aromatic Species (ppmv)						
Benzene	–		–		–	
Toluene	–		–		–	
Xylene + Ethylbenzene	–		–		–	
Phenols	Tr	NF–Tr	–		Tr	NF–Tr
Higher Aromatics	–		–		–	
Nitrogen Species (ppmv)						
NH_3	Tr	NF–30	–		Tr	NF–30
HCN	–		–		–	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-17. ATOMIC ABSORPTION DATA FOR THE CLEAN PRODUCT GAS (7.4)

Component ($\mu g/m^3$)	Phase II Value
Fe (as $Fe(CO)_5$)	260
Ni (as $Ni(CO)_4$)	15
Mn (as $Mn(CO)_5$)	44.3

TABLE A.2-18. TEST DATA FOR GAS PHASE SAMPLE POINT 7.7, INTERMEDIATE PROCESS GAS STREAM

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)			–		–	
Temperature (°C)			–		–	
Molecular Wt. of Dry Gas			20.0		20.0	
Moisture Content (wt %)			–		–	
Composition Data (Dry Gas Basis)						
Fixed Gas, (vol %)						
H_2	NO PHASE I DATA		44		44	
O_2			0.68	0.67–0.68	0.68	0.67–0.68
N_2			1.4	1.4–1.5	1.4	1.4–1.5
CH_4			12.5	11–14	12.5	11–14
CO			8.9	8.5–12	8.9	8.5–12
CO_2			31	29–32	31	29–32
Sulfur Species (ppmv)						
H_2S			1.4	0.9–1.4	1.4	0.9–1.4
COS			0.4	0.3–3.3	0.4	0.3–3.3
CH_3SH			6.6	6.6–25	6.6	6.6–25
C_2H_5SH			11	11–37	11	11–37
C_1–C_6+ Hydrocarbons (vol %)						
Ethane			0.5		0.5	
Ethylene			–		–	
C_3			0.05	0.008–1.1	0.05	0.008–1.1
C_4			–		–	
C_5			–		–	
C_6+			0.26	0.18–0.26	0.26	0.18–0.26
Aromatic Species (ppmv)						
Benzene			–		–	
Toluene			–		–	
Xylene + Ethylbenzene			–		–	
Phenols			–		–	
Higher Aromatics			–		–	
Nitrogen Species (ppmv)						
NH_3			–		–	
HCN			–		–	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-19. TEST DATA FOR GAS PHASE SAMPLE POINT 13.1, TAR TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	0.55		0.76		0.55	0.55–0.76
Temperature (°C)	61		52		52	52–61
Molecular Wt. of Dry Gas	29.4		29.1		29.1	
Moisture Content (wt %)	–		14		14	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	Tr	NF–Tr	–		Tr	NF–Tr
O_2	20	15.5–20	19	14–20	19	14–20
N_2	72	72–81	77.5	71–77.5	77.5	71–81
CH_4	0.1	0.08–0.1	0.16	0.14–0.18	0.16	0.08–0.18
CO	NF		Tr		Tr	NF–Tr
CO_2	3.1	1.1–3.1	0.86	0.76–2.85	0.86	0.76–3.1
Sulfur Species (ppmv)						
H_2S	13000	1600–13000	6900	3500–13000	6900	1600–13000
COS	NF		110	51–110	110	NF–110
CH_3SH	610	57–610	390	390–400	390	57–610
C_2H_5SH	240	135–240	240	220–260	240	135–260
C_1–C_6+ Hydrocarbons (vol %)						
Ethane	Tr		Tr		Tr	
Ethylene			–		–	
C_3	0.004	Tr–0.03	0.01	0.008–0.01	0.01	Tr–0.03
C_4	0.005	Tr–0.24	Tr		Tr	Tr–0.24
C_5	Tr	NF–Tr	Tr		Tr	NF–Tr
C_6+	0.001		0.37	0.12–0.42	0.37	0.001–0.42
Aromatic Species (ppmv)						
Benzene	4300		2000	1800–2100	2000	1800–2100
Toluene	100		960	876–1100	960	876–1100
Xylene + Ethylbenzene	–		220	190–250	220	190–250
Phenols	57	5.2–57	–		57	5.2–57
Higher Aromatics	–		2.2	2.2–2.25	2.2	2.2–2.25
Nitrogen Species (ppmv)						
NH_3	2600	2000–2600	–		2600	2000–2600
HCN	130		–		130	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-20. TEST DATA FOR GAS PHASE SAMPLE POINT 13.2, UNPURE TAR TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				–	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II DATA		NF	
O_2	20.3				20.3	
N_2	78.2				78.2	
CH_4	–				–	
CO	0.2				0.2	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	430	NF-430			430	NF-430
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	Tr	NF-Tr			Tr	NF-Tr
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	230	NF-230			230	NF-230
HCN	–				–	
Acid Gases (vol %)	0.7	0.2-0.7			0.7	0.2-0.7
Saturated Hydrocarbons (vol %)	0.6				0.6	
Unsaturated Hydrocarbons (vol %)	0.2	NF-0.2			0.2	NF-0.2

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-21. TEST DATA FOR GAS PHASE SAMPLE POINT 13.3, MEDIUM OIL TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	18.6		1.7		1.7	1.7-18.6
Temperature (°C)	48		42		42	42-48
Molecular Wt. of Dry Gas	30.6		32.5		32.5	
Moisture Content (wt %)	–		8.4		8.4	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF	NF-23	Tr		Tr	NF-23
O_2	0.89	0.6-0.89	0.45	0.29-0.82	0.45	0.29-0.89
N_2	3.4	1.1-3.4	1.1	0.5-4.3	1.1	0.5-4.3
CH_4	7.6	2.7-7.6	7.6	6.8-8.5	7.6	2.7-8.5
CO	5.3	3.1-5.3	5.9	5.6-13.3	5.9	3.1-13.3
CO_2	51	51-87	56	54-58	56	51-87
Sulfur Species (ppmv)						
H_2S	35000	32000-41000	26000	26000-26050	26000	26000-41000
COS	NQ		96	81-96	96	81-96
CH_3SH	1000		5200	4900-5500	5200	1000-5500
C_2H_5SH	460		2100	1800-2400	2100	460-2400
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	0.62	0.37-0.62	0.34	0.33-0.35	0.34	0.33-0.35
Ethylene			Tr		Tr	
C_3	0.16	0.16-0.34	0.30	0.29-0.30	0.30	0.16-0.34
C_4	0.21	0.21-0.42	0.25	0.19-0.31	0.25	0.19-0.42
C_5	0.08	0.08-0.21	0.09	0.08-0.10	0.09	0.08-0.21
C_6+			2.4	2.3-2.5	2.4	2.3-2.5
Aromatic Species (ppmv)						
Benzene	4900		7650	7400-7900	7650	7400-7900
Toluene	1700		1400	1300-1400	1400	1300-1400
Xylene + Ethylbenzene	–		140	130-150	140	130-150
Phenols	110	Tr-110	–		110	Tr-110
Higher Aromatics	–		–		–	
Nitrogen Species (ppmv)						
NH_3	19	5.3-19	–		19	5.3-19
HCN	57		–		57	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

NQ = Present but not quantifiable

*Values are best values from available data

TABLE A.2-22. TEST DATA FOR GAS PHASE SAMPLE POINT 13.4, UNPURE OIL TANK VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				–	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II DATA		NF	
O_2	17	15-19			17	15-19
N_2	75				75	
CH_4	–				–	
CO	NF				NF	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	1500	180-1500			1500	180-1500
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	NF				NF	
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	840	NF-840			840	NF-840
HCN	–				–	
Acid Gases (vol %)	5.0	1.4-5.0			5.0	1.4-5.0
Saturated Hydrocarbons (vol %)	0.6	NF-0.6			0.6	NF-0.6
Unsaturated Hydrocarbons (vol %)	0.5	NF-1.0			0.5	NF-1.0

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-23. TEST DATA FOR GAS PHASE SAMPLE POINT 13.5, CONDENSATE TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	3.38				3.38	
Temperature (°C)	7				7	
Molecular Wt. of Dry Gas	26.6				26.6	
Moisture Content (wt %)	~1.0				~1.0	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	14.6	13.8-14.6	NO PHASE II DATA		14.6	13.8-14.6
O_2	16.6	15.1-16.6			16.6	15.1-16.6
N_2	61.0	58.0-61.0			61.0	58.0-61.0
CH_4	1.2	1.19-2.1			1.2	1.19-2.1
CO	NF	NF-3.6			NF	NF-3.6
CO_2	6.2	6.15-9.1			6.2	6.15-9.1
Sulfur Species (ppmv)						
H_2S	6200	2400-6900			6200	2400-6900
COS	NQ				-	
CH_3SH	210				210	
C_2H_5SH	72				72	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	0.07	0.07-0.40			0.07	0.07-0.40
Ethylene						
C_3	0.05	0.02-0.21			0.05	0.02-0.21
C_4	0.03	0.02-0.27			0.03	0.02-0.27
C_5	0.04	Tr-0.13			0.04	Tr-0.13
C_6+	-				-	
Aromatic Species (ppmv)						
Benzene	5200				5200	
Toluene	3000				3000	
Xylene + Ethylbenzene	-				-	
Phenols	Tr	Tr-12			Tr	Tr-12
Higher Aromatics	-				-	
Nitrogen Species (ppmv)						
NH_3	NF	NF-820			NF	NF-820
HCN	170				170	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

NQ = Present but not quantifiable

*Values are best values from available data

TABLE A.2-24. TEST DATA FOR GAS PHASE SAMPLE POINT 13.6, TAR/OIL SEPARATION SECTION WASTE GAS TO FLARE

Component	Phase I		Phase II		Overall	
	Value	Range	Value	Range	*Value	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–		**		**	
Temperature (°C)	–		40.2		40.2	
Molecular Wt. of Dry Gas	37.6		39		39	
Moisture Content (wt %)	–		7.7		7.7	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	11	9.8–11	~10		11	9.8–1
O_2	0.47	0.47–1.1	Tr	Tr–0.7	Tr	Tr–1
N_2	0.56	0.56–1.8	Tr	Tr–0.7	Tr	Tr–1
CH_4	6.1	5.9–6.1	3.6	3.4–5.6	3.5	3.4–6
CO	7.2	6.4–7.2	1.1	1.0–4.9	1.1	1.0–7
CO_2	72	71–72	80.5	72–81	77.5	71–
Sulfur Species (ppmv)						
H_2S	14000	2800–19000	9400	8200–12000	9000	2800–1
COS	NQ		120	87–150	120	87–1
CH_3SH	910		2600	1900–3400	2500	910–
C_2H_5SH	280		1700	1450–2300	1600	280–
C_2–C_6+ Hydrocarbons (vol %)						
Ethane	0.4	0.4–1.1	0.34	0.32–0.36	0.33	0.32–
Ethylene			Tr	Tr–0.01	Tr	Tr–
C_3	0.33	0.21–0.62	0.43	0.22–0.45	0.41	0.21–
C_4	0.27	0.09–0.72	0.43	0.19–0.45	0.41	0.09–
C_5	0.15	Tr–0.15	0.09	0.08–0.24	0.09	Tr–
C_6+			1.4	1.3–2.0	1.3	1.3–
Aromatic Species (ppmv)						
Benzene	9500		10000	9800–10000	9600	9600–
Toluene	4000		1200	1160–1250	1200	1160–
Xylene + Ethylbenzene	–		150	130–180	150	130–
Phenols	4.2	Tr–18	–		4.2	Tr–
Higher Aromatics	–		5.1	4.9–5.3	4.9	4.9–
Nitrogen Species (ppmv)						
NH_3	20000	420–20000	–		19500	420–
HCN	64		–		64	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

NQ = Present but not quantifiable.

– = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

* Values are best values from available data.

** <200 m^3/gasifier-hr, design value is 28 m^3/gasifier-hr at 25°C

TABLE A.2-25. TEST DATA FOR GAS PHASE SAMPLE POINT 13.7, PHENOLIC WATER TANK VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	13		5.5		5.5	5.5-13
Temperature (°C)	76		76		76	
Molecular Wt. of Dry Gas	34.2		27.4		34.4	
Moisture Content (wt %)	-		42		42	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	Tr	Tr-0.2	-		Tr	Tr-0.2
O_2	13	10.8-13	13	11-13	13	10.8-13
N_2	53	48.7-53.0	39	38-53	39	38-53
CH_4	0.2		-		0.2	
CO	NF		-		NF	
CO_2	29	29-39	35	26-35	35	26-39
Sulfur Species (ppmv)						
H_2S	6400	6400-17000	12600	4000-13000	12600	4000-17000
COS	NF		41	28-41	41	NF-41
CH_3SH	650		2100	1200-2100	2100	650-2100
C_2H_5SH	400		7200	5200-7200	7200	400-7200
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	0.02	0.01-0.11	-		0.02	0.01-0.11
Ethylene						
C_3	0.01	0.01-0.08	0.02	0.01-0.02	0.02	0.01-0.08
C_4	0.05	0.02-0.05	0.02	0.02-0.02	0.02	0.02-0.05
C_5	0.09	NF-0.09	0.006	0.006-0.06	0.006	NF-0.09
C_6+	-		1.8	1.6-2.0	1.8	1.6-2.0
Aromatic Species (ppmv)						
Benzene	16000		11000	10500-11400	11000	10500-11400
Toluene	6000		2300	2200-2400	2300	2200-2400
Xylene + Ethylbenzene	-		280	200-310	280	200-310
Phenols	Tr	NF-34	-		Tr	NF-34
Higher Aromatics	-		3.1		3.1	
Nitrogen Species (ppmv)						
NH_3	12000	2700-12000	-		12000	2700-12000
HCN	38		-		38	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-26. TEST DATA FOR GAS PHASE SAMPLE POINT 14.1, DEGASSING CYCLONE VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				–	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	–		NO PHASE II DATA		–	
O_2	–				–	
N_2	–				–	
CH_4	–				–	
CO	–				–	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	2100				2100	
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1–C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	NF				NF	
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	790	17–790			790	17–790
HCN	–				–	
Acid Gases (vol %)	12				12	
Saturated Hydrocrabons (vol %)	–				–	
Unsaturated Hydrocarbons (vol %)	0.4				0.4	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-27. TEST DATA FOR GAS PHASE SAMPLE POINT 14.2, GAS TANK VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				–	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	1.2		NO PHASE II DATA		1.2	
O_2	20				20	
N_2	74				74	
CH_4	–				–	
CO	NF				NF	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	485	430-540			485	430-540
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	–				–	
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	–				–	
HCN	–				–	
Acid Gases (vol %)	5.1	3.6-6.6			5.1	3.6-6.6
Saturated Hydrocarbons (vol %)	1.0				1.0	
Unsaturated Hydrocarbons (vol %)	0.2	NF-0.2			0.2	NF-0.2

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-28. TEST DATA FOR GAS PHASE SAMPLE POINT 14.3, UNCLEAN OIL TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				–	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II DATA		NF	
O_2	21				21	
N_2	79				79	
CH_4	–				–	
CO	NF				NF	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	NF				NF	
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	Tr	NF-Tr			Tr	NF-Tr
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	490				490	
HCN	–				–	
Acid Gases (vol %)	0.6				0.6	
Saturated Hydrocarbons (vol %)	NF				NF	
Unsaturated Hydrocarbons (vol %)	NF				NF	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-29. TEST DATA FOR GAS PHASE SAMPLE POINT 14.4, PHENOLIC WATER TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	-				-	
Temperature (°C)	-				-	
Molecular Wt. of Dry Gas	-				-	
Moisture Content (wt %)	-				-	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	0.2		NO PHASE II DATA		0.2	
O_2	20				20	
N_2	79				79	
CH_4	-				-	
CO	NF				NF	
CO_2	-				-	
Sulfur Species (ppmv)						
H_2S	NF				NF	
COS	-				-	
CH_3SH	-				-	
C_2H_5SH	-				-	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	-				-	
Ethylene	-				-	
C_3	-				-	
C_4	-				-	
C_5	-				-	
C_6+	-				-	
Aromatic Species (ppmv)						
Benzene	-				-	
Toluene	-				-	
Xylene + Ethylbenzene	-				-	
Phenols	-				-	
Higher Aromatics	-				-	
Nitrogen Species (ppmv)						
NH_3	-				-	
HCN	-				-	
Acid Gases (vol %)	1.1	0.7-1.4			1.1	0.7-1.4
Saturated Hydrocarbons (vol %)	1.0				1.0	
Unsaturated Hydrocarbons (vol %)	0.2	NF-0.2			0.2	NF-0.2

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

*Values are best values from available data

TABLE A.2-30. TEST DATA FOR GAS PHASE SAMPLE POINT 14.5 AMMONIA STRIPPER (1ST DEGASSING) VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	91	65-133	260		260	65-260
Temperature (°C)	83		91		91	83-91
Molecular Wt. of Dry Gas	28.6		47.7		32.7	
Moisture Content (wt %)	85	82-88	76		76	76-88
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		-		NF	
O_2	9.5	2.3-16.1	5.5	4.9-6.0	-	NF-16.1
N_2	61	2.0-61	28	26-30	-	NF-61
CH_4	Tr	NF-Tr	-		Tr	NF-Tr
CO	NF		-		NF	
CO_2	35	24-91	64	63-64	55	24-91
Sulfur Species (ppmv)						
H_2S	46000	22000-47000	22700		19500	19500-47000
COS	NF		-		NF	
CH_3SH	140		340	270-400	290	140-400
C_2H_5SH	32		120	100-140	100	32-140
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	Tr	NF-0.02	-		Tr	NF-0.02
Ethylene						
C_3	Tr	NF-0.01	-		Tr	NF-0.01
C_4	Tr	NF-0.04	Tr		Tr	NF-0.04
C_5	Tr	NF-Tr	-		Tr	NF-Tr
C_6+	NF		Tr		NF	NF-Tr
Aromatic Species (ppmv)						
Benzene	-		Tr		Tr	
Toluene	-		-		-	
Xylene + Ethylbenzene	-		Tr		Tr	
Phenols	14500	540-38000	7200		6200	540-38000
Higher Aromatics	-		-		-	
Nitrogen Species (ppmv)						
NH_3	570000	2400-570000	486000		418000	2400-570000
HCN	1400	250-1400	5600	Tr-5600	4800	Tr-5600

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

+ Overall values are normalized to total 100%.

*Values are best values from available data

TABLE A.2-31. TEST DATA FOR GAS PHASE SAMPLE POINT 14.6, COOLER VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				4.4	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	–		NO PHASE II DATA		–	
O_2	–				–	
N_2	–				–	
CH_4	–				–	
CO	–				–	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	NF				NF	
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1–C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	Tr				Tr	
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	82000	74000-90000			82000	74000-90000
HCN	–				–	
Acid Gases (vol %)	24				24	
Saturated Hydrocarbons (vol %)	–				–	
Unsaturated Hydrocarbons (vol %)	0.8				0.8	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-32. TEST DATA FOR GAS PHASE SAMPLE POINT 14.7, SECOND DEGASSING VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	-				-	
Temperature (°C)	-				-	
Molecular Wt. of Dry Gas	-				-	
Moisture Content (wt %)	-				-	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II DATA		NF	
O_2	21				21	
N_2	78				78	
CH_4	-				-	
CO	NF				NF	
CO_2	-				-	
Sulfur Species (ppmv)						
H_2S	NF				NF	
COS	-				-	
CH_3SH	-				-	
C_2H_5SH	-				-	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	-				-	
Ethylene	-				-	
C_3	-				-	
C_4	-				-	
C_5	-				-	
C_6+	-				-	
Aromatic Species (ppmv)						
Benzene	-				-	
Toluene	-				-	
Xylene + Ethylbenzene	-				-	
Phenols	NF				NF	
Higher Aromatics	-				-	
Nitrogen Species (ppmv)						
NH_3	200	NF-200			200	NF-200
HCN	-				-	
Acid Gases (vol %)	0.5	NF-0.5			0.5	NF-0.5
Saturated Hydrocarbons (vol %)	0.9				0.9	
Unsaturated Hydrocarbons (vol %)	NF				NF	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

*Values are best values from available data

TABLE A.2-33. TEST DATA FOR GAS PHASE SAMPLE POINT 14.8, SLOP TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				–	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II DATA		NF	
O_2	21				21	
N_2	77				77	
CH_4	–				–	
CO	NF				NF	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	NF				NF	
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	Tr	NF-Tr			Tr	NF-Tr
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	77	17-77			77	17-77
HCN	–				–	
Acid Gases (vol %)	NF				NF	
Saturated Hydrocarbons (vol %)	0.9				0.9	
Unsaturated Hydrocarbons (vol %)	1.2	NF-1.2			1.2	NF-1.2

NF = Not Found. <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-34. TEST DATA FOR GAS PHASE SAMPLE POINT 14.9, CRUDE PHENOL TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	0.20	0.13-0.26			0.20	0.13-0.26
Temperature (°C)	11				11	
Molecular Wt. of Dry Gas	28.0				28.0	
Moisture Content (wt %)	~1.3				~1.3	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF				NF	
O_2	20	18-21			20	18-21
N_2	77	76-81			77	76-81
CH_4	Tr				Tr	
CO	NF				NF	
CO_2	NF				NF	
Sulfur Species (ppmv)						
H_2S	180	NF-7000			180	NF-7000
COS	NF				NF	
CH_3SH	NF				NF	
C_2H_5SH	NF				NF	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	Tr				Tr	
Ethylene	-				-	
C_3	Tr				Tr	
C_4	Tr				Tr	
C_5	Tr				Tr	
C_6+	NF				NF	
Aromatic Species (ppmv)						
Benzene	-				-	
Toluene	-				-	
Xylene + Ethylbenzene	-				-	
Phenols	22	22-74			22	22-74
Higher Aromatics	-				-	
Nitrogen Species (ppmv)						
NH_3	12	NF-260			12	NF-260
HCN	34				34	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-35. TEST DATA FOR GAS PHASE SAMPLE POINT 14.10, DI-ISOPROPYL ETHER TANK VENT

Component	Phase I		Phase II		Overall	
	Value *	Range	Value *	Range	Value *	Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				–	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II DATA		NF	
O_2	21				21	
N_2	79				79	
CH_4	–				–	
CO	NF				NF	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	NF				NF	
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	Tr	NF-Tr			Tr	NF-Tr
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	51				51	
HCN	–				–	
Acid Gases	NF				NF	
Saturated Hydrocarbons (vol %)	0.7				0.7	
Unsaturated Hydrocarbons (vol %)	NF				Nf	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-36. TEST DATA FOR GAS PHASE SAMPLE POINT 15.1, LIGHT TAR STORAGE TANK VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				0.55	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II DATA		NF	
O_2	19				19	
N_2	81				81	
CH_4	–				–	
CO	NF				NF	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	890	230–890			890	230–890
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1–C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	Tr				Tr	
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	100				100	
HCN	–				–	
Acid Gases (vol %)	0.4	NF–0.4			0.4	NF–0.4
Saturated Hydrocarbons (vol %)	NF				NF	
Unsaturated Hydrocarbons (vol %)	1.4	0.2–1.4			1.4	0.2–1.4

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-37. TEST DATA FOR GAS PHASE SAMPLE POINT 15.2, MEDIUM OIL STORAGE TANK VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				–	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II DTA		NF	
O_2	6.2				6.2	
N_2	88				88	
CH_4	–				–	
CO	NF				NF	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	1550	1500-1600			1500	1500-1600
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	Tr				Tr	
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	75				75	
HCN	–				–	
Acid Gases (vol %)	5.0	0.6-5.0			5.0	0.6-5.0
Saturated Hydrocarbons (vol %)	0.4				0.4	
Unsaturated Hydrocarbons (vol %)	1.2	NF-1.2			1.2	NF-1.2

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %).

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-38. TEST DATA FOR GAS PHASE SAMPLE POINT 15.3, NAPHTHA STORAGE TANK VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	0.033		4.5		4.5	0.033-4.5
Temperature (°C)	-		32		32	
Molecular Wt. of Dry Gas	29.5		32.4		33.3	
Moisture Content (wt %)	-		5.0		5.0	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF				NF	
O_2	3.9	3.9-9.0	2.6	2.5-2.6	2.6	2.5-9.0
N_2	95	91-95	84	84-84	84	84-95
CH_4	NF		-		NF	
CO	NF		-		NF	
CO_2	NF		0.85		0.85	NF-0.85
Sulfur Species (ppmv)						
H_2S	NF	NF-1600			NF	NF-1600
COS	NF				NF	
CH_3SH	4100		2600	2400-2700	2600	2400-4100
C_2H_5SH	6700		9700	6900-12000	9700	6700-12000
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	0.009	0.007-0.009	Tr		Tr	Tr-0.009
Ethylene						
C_3	0.007	0.004-0.10	0.01	0.01-0.01	0.01	0.004-0.10
C_4	0.10	0.03-0.10	0.07	0.07-0.07	0.07	0.03-0.10
C_5	0.39	0.10-0.39	0.08	0.07-0.08	0.08	0.07-0.39
C_6+	-		5.3	5.1-5.4	5.3	5.1-5.4
Aromatic Species (ppmv)						
Benzene	4000		37600	37200-38000	37600	37200-38000
Toluene	1300		1900	1600-2100	1900	1600-2100
Xylene + Ethylbenzene	-		60	57-63	60	57-63
Phenols	Tr	NF-Tr	-		Tr	NF-Tr
Higher Aromatics	-		-		-	
Nitrogen Species (ppmv)						
NH_3	NF	NF-23	-		NF	NF-23
HCN	1100		-		1100	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

- = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data

TABLE A.2-39. TEST DATA FOR GAS PHASE SAMPLE POINT 15.4, CRUDE PHENOL STORAGE TANK VENT

Component	Phase I Value *	Phase I Range	Phase II Value *	Phase II Range	Overall Value *	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)	–				–	
Temperature (°C)	–				–	
Molecular Wt. of Dry Gas	–				–	
Moisture Content (wt %)	–				–	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	NF		NO PHASE II DATA		NF	
O_2	16				16	
N_2	84				84	
CH_4	–				–	
CO	NF				NF	
CO_2	–				–	
Sulfur Species (ppmv)						
H_2S	NF				NF	
COS	–				–	
CH_3SH	–				–	
C_2H_5SH	–				–	
C_1–C_6+ Hydrocarbons (vol %)						
Ethane	–				–	
Ethylene	–				–	
C_3	–				–	
C_4	–				–	
C_5	–				–	
C_6+	–				–	
Aromatic Species (ppmv)						
Benzene	–				–	
Toluene	–				–	
Xylene + Ethylbenzene	–				–	
Phenols	Tr	NF-Tr			Tr	NF-Tr
Higher Aromatics	–				–	
Nitrogen Species (ppmv)						
NH_3	3.7				3.7	
HCN	–				–	
Acid Gases (vol %)	NF				NF	
Saturated Hydrocarbons (vol %)	0.4				0.4	
Unsaturated Hydrocarbons (vol %)	NF				NF	

NF = Not Found, <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

*Values are best values from available data

TABLE A.2-40. TEST DATA FOR GAS PHASE SAMPLE POINT 20.1, COMBINED GAS TO FLARE

Component	Phase I Value*	Phase I Range	Phase II Value*	Phase II Range	Overall Value*	Overall Range
Dry Gas Flow Rate (m^3 at 25°C/gasifier-hr)						
Steady	3200		1100	1100-3300	1100	1100-3300
**Discharge	–		230		230	
Temperature (°C)	15		21		21	15-21
Molecular Wt. of Dry Gas	42.0		41.7		41.7	
Moisture Content (wt %)	–		2.5		2.5	
Composition Data (Dry Gas Basis)						
Fixed Gases (vol %)						
H_2	Tr	NF-Tr	Tr		Tr	NF-Tr
O_2	Tr	Tr-0.37	0.13	Tr 0.26	0.10	Tr-0.37
N_2	0.50	0.50-1.9	0.14	Tr-0.29	0.21	Tr-1.9
CH_4	10	4.8-10	5.2	4.1-6.4	6.2	4.1-10
CO	NF		2.4	1.1-3.7	1.9	NF-3.7
CO_2	88	87-92	88	87-90	88	87-92
Sulfur Species (ppmv)						
H_2S	14000	8500-19000	10600	10000-15000	10600	8500-15000
COS	~280		250	240-260	250	240-280
CH_3SH	1500		2500	2200-2900	2500	1500-2900
C_2H_5SH	~600		190	140-270	190	140-600
C_1-C_6+ Hydrocarbons (vol %)						
Ethane	1.01	0.19-1.9	0.77	0.73-0.80	0.77	0.19-0.80
Ethylene			Tr		Tr	
C_3	1.03	0.11-1.5	0.65	0.61-0.67	0.65	0.11-1.5
C_4	0.59	0.09-1.1	0.38	0.32-0.50	0.38	0.09-1.1
C_5	0.14	0.04-0.17	0.04	0.02-0.06	0.04	0.02-0.17
C_6+	–		0.06	0.02-0.12	0.06	0.02-0.12
Aromatic Species (ppmv)						
Benzene	–		640	460-830	640	460-830
Toluene	–		215	87-340	215	87-340
Xylene + Ethylbenzene	–		33		33	
Phenols	Tr		–		Tr	
Higher Aromatics	–		–		–	
Nitrogen Species (ppmv)						
NH_3	NF		–		NF	
HCN	100		–		100	

NF = Not Found. <0.01 vol % for fixed gases and <1 ppmv for all others (1000 ppmv = 1 vol %)

Tr = Trace. ~0.01 vol % for fixed gases and ~1 ppmv for all others

– = No data available

Phase I Ethane data are the total of all C_2 Hydrocarbons

*Values are best values from available data.

**Flow rate during discharge from the gasifier through the high pressure coal lock vent, time averaged.

TABLE A.2-41. ATOMIC ABSORPTION DATA FOR THE COMBINED GAS TO FLARE (20.1)

Component (μg/m³)	Phase II Value
As	1.9
Be	NF
Cd	0.24
Co	0.17
Cr	NF
Cu	5.8
Hg	NF
Mo	NF
Ni	7.5
Pb	1.0
Sb	NF
Se	7.2
Sr	4.4
Tl	NF
V	NF
Zn	31

NF = Not found

A3.0. COMPILATION OF PARTICUALTE DATA FOR GASEOUS STREAMS

TABLE A.3-1. PARTICULATE DATA FOR GAS PHASE SAMPLE POINT 1.2, FLEISSNER AUTOCLAVE VENT

Component (mg/m³ at 25°C)	Phase I Value	Phase I Range	Phase II Value	Phase II Range	Overall Value	Overall Range
	NO PHASE I DATA					
Total Particulate			1080		1080	
Particulate			280		280	
Condensed Organics (Extracted)			480		480	
Dissolved Solids			320		320	

TABLE A.3-2. PARTICULATE DATA FOR GAS PHASE SAMPLE POINT 2.2, DEDUSTING CYCLONE VENT

Component (mg/m³ at 25°C)	Phase I Value	Phase I Range	Phase II Value	Phase II Range	Overall Value	Overall Range
Total Particulate	43	43-50	90	90-175	90	43-175
Particulate	-		-		-	
Condensed Organics (Extracted)	-		-		-	
Dissolved Solids	-		-		-	

- No data available

TABLE A.3-3. PARTICULATE DATA FOR GAS PHASE SAMPLE POINT 3.2, LOW PRESSURE COAL LOCK VENT

Component (mg/m^3 at 25°C)	Phase I		Phase II		Overall	
	Value	Range	Value	Range	Value	Range
Total Particulate	13800	12700-13800	8100	8100	8100	8100-13800
Particulate	-		220		220	
Condensed Organics (Extracted)	-		7300		7300	
Dissolved Solids	-		650		650	

- No data available

TABLE A.3-4. PARTICULATE DATA FOR GAS PHASE SAMPLE POINT 3.3, GASIFIER START-UP VENT

Component (mg/m^3 at 25°C)	Phase I		Phase II		Overall	
	Value	Range	Value	Range	Value	Range
	NO PHASE I DATA					
Total Particulate			9450		9450	
Particulate			61		61	
Condensed Organics (Extracted)			8980		8980	
Dissolved Solids			400		400	

TABLE A.3-5. PARTICULATE DATA FOR GAS PHASE SAMPLE POINT 3.5, ASH LOCK CYCLONE VENT

Component (mg/m^3 at 25°C)	Phase I		Phase II		Overall	
	Value	Range	Value	Range	Value	Range
Total Particulate	10300	1200-11600	NO PHASE II DATA		10300	120-11600
Particulate	-				-	
Condensed Organics (Extracted)	-				-	
Dissolved Solids	-				-	

- No data available

TABLE A.3-6. PARTICULATE DATA FOR GAS PHASE SAMPLE POINT 3.6, HIGH PRESSURE COAL LOCK VENT

Component (mg/m^3 at 25°C)	Phase I		Phase II		Overall	
	Value	Range	Value	Range	Value	Range
Total Particulate	970	200-1260	960		960	200-1260
Particulate	-		61		61	
Condensed Organics (Extracted)	-		660		660	
Dissolved Solids	-		240		240	

- No data available

TABLE A.3-7. PARTICULATE DATA FOR GAS PHASE SAMPLE POINT 13.6, TAR/OIL SEPARATION SECTION WASTE GAS TO FLARE

Component (mg/m³ at 25°C)	Phase I Value	Phase I Range	Phase II Value	Phase II Range	Overall Value	Overall Range
	NO PHASE I DATA					
Total Particulate			920		920	
Particulate			29		29	
Condensed Organics (Extracted)			660		660	
Dissolved Solids			230		230	

TABLE A.3-8. PARTICULATE DATA FOR GAS PHASE SAMPLE POINT 20.1, COMBINED GAS TO FLARE

Component (mg/m³ at 25°C)	Phase I Value	Phase I Range	Phase II Value	Phase II Range	Overall Value	Overall Range
	NO PHASE I DATA					
Total Particulate			410		410	
Particulate			47		47	
Condensed Organics (Extracted)			310		310	
Dissolved Solids			54		54	

A4.0. COMPILATION OF DATA FOR AQUEOUS STREAMS

TABLE A.4-1. ATOMIC ABSORPTION DATA FOR THE FLEISSNER CONDENSATE (1.3)

Component (mg/L)	Phase II Value
As	0.85
Be	0.005
Cd	0.0024
Co	0.022
Cr	0.25
Cu	0.005
Hg	0.08
Mo	0.031
Ni	0.56
Pb	0.038
Sb	NF
Se	0.016
Sr	2.1
Tl	NF
V	0.10
Zn	1.2

NF = not found

TABLEA A.4-2. WATER QUALITY PARAMETERS FOR THE CYANIC WATER (7.5)

Component	Overall Value*	Range
Flow Rate (m^3/gasifier-hr)	–	
Temperature (°C)	80	
pH	11.9	11.4-12.1
Total Solids (mg/L)	730	
Total Non-Volatile Solds (mg/L)	560	
Total Suspended Solids (mg/L)	140	
Total Dissolved Solids (mg/L)	590	
Water Quality Parameters		
COD (as mgO_2/L)	205	
Permanganate	570	
BOD_5 (as mgO_2/L)		
Composition Data (mg/L)		
TOC	–	
Tars and Oils	–	
Total Phenols	–	
Volatile Phenols	–	
Other Phenols	–	
Free Ammonia	–	
Fixed Ammonia	–	
Cyanide	–	
Nitrites	–	
Nitrates	–	
Pyridines	–	
Chlorides	–	
Florides	–	
Sulfites	–	
Sulfates	–	
Hydrogen Sulfide	–	
Thiocyanate	–	
Thiosulfates	–	
Sulfur	60	52-68

– = No data available
*Values are best values from available data

TABLE A.4-3. SPARK SOURCE MASS SPECTRAL RATE FOR THE CYANIC WATER (7.5)

Component (mg/L)	Overall Value
U	≤0.01
Th	≤0.01
Pb	0.008
Ce	0.004
La	0.008
Ba	0.02
I	0.4
Y	0.03
Sr	0.01
Rb	<0.001
Br	0.1
Se	0.02
As	0.09
Ge	0.02
Zn	0.05
Cu	0.02
Ni	0.007
Co	≤0.003
Fe	4
Mn	0.04
Cr	0.009
V	0.001
Ti	0.4
Sc	≤0.002
K	7
Cl	4
P	0.03
Si	1
Al	0.07
Na	>4
F	≃0.3
B	0.02
Li	0.002
S	>10
Mg	>10

TABLE A.4-4. WATER QUALITY PARAMETERS FOR THE QUENCHED ASH WASTEWATER (12.3)

Component	Overall Value*	Range
Flow Rate (m^3/gasifier-hr)	–	
Temperature (°C)	–	
pH	8.1	8.1-12.1
Total Solids (mg/L)	10900	1300-11500
Total Non-Volatile Solids (mg/L)	5700	130-5700
Total Suspended Solids (mg/L)	8760	570-8760
Total Dissolved Solids (mg/L)	2100	760-2600
Water Quality Parameters		
COD (as mgO_2/L)	1460	
Permanganate (as mgO_2/L)	8060	
BOD_5 (as mgO_2/L)	90	30-90
Composition Data (mg/L)		
TOC	–	
Tars and Oils	NF	
Total Phenols	–	
Volatile Phenols	0.17	0.04-0.3
Other Phenols	–	
Free Ammonia	Tr	
Fixed Ammonia	1.9	1.5-2.5
Cyanide	0.01	Tr-0.01
Nitrites	0.40	0.05-0.82
Nitrates	4.8	4.0-5.6
Pyridines	–	
Chlorides	28.0	20-37
Florides	0.91	0.65-1.2
Sulfites	Tr	
Sulfates	495	320-670
Hydrogen Sulfide	Tr	
Thiocyanate	0.026	0.01-0.04
Thiosulfates	Tr	

– = No data available
Tr = Trace
NF = Not found
*Values are best values from available data

TABLE A.4-5. WATER QUALITY PARAMATERS FOR THE PHENOSOLVAN INLET WATER (14.0)

Component	Overall Value*	Range
Flow Rate (m^3/gasifier-hr)	–	
Temperature (°C)	60	
pH	9.17	9.14-9.17
Total Solids (mg/L)	2320	
Total Non-Volatile Solids (mg/L)	52	
Total Suspended Solids (mg/L)	150	
Total Dissolved Solids (mg/L)	2170	
Water Quality Parameters		
COD (as mgO_2/L)	18900	17700-18900
Permanganate (as mgO_2/L)	14200	
BOD_5 (as mgO_2/L)	9030	
True Color (Pt-Co)	17500	
Composition Data (mg/L)		
TOC	4970	
Tars and Oils	400	
Total Phenols	2120	
Volatile Phenols	–	
Other Phenols	–	
Free Ammonia	3510	
Fixed Ammonia	250	
Cynide	<1	
Nitrites	–	
Nitrates	<1	
Pyridines	–	
Chlorides	–	
Florides	–	
Sulfites	–	
Sulfates	–	
Hydrogen Sulfide	–	
Thiocyanate	>75	
Thiosulfates	–	
PO_4	<2.5	

– = No data available

*Values are best values from available data

TABLE A.4-6. TRACE ORGANIC SPECIES DATA FOR THE PHENOSOLVAN INLET WATER (14.0)

Component (mg/L)	Overall Value
BTX Analysis*	
Benzene	0.9
Toluene	0.5
Xylene	0.8
Nitrogen Species Analysis**	
Pyridine	28
2-Methylpyridine	29
3- and 4-Methylpyridine(s)	13
Dimethyl- or Ethylpyridine(s)	39
Dimethyl- or Ethylpyridine(s)	7
Alkylpyridine(s)	16
Alkylpyridine(s)	10
Quinoline	5
Alkylquinoline(s)	12
PNA Analysis***	
Benz(a)anthracene	0.92
7,12-Dimethylbenz(a)anthracene	0.23
Benzo(b)fluoranthrene	0.68
Benzo(a)pyrene	0.19
3-Methylcholanthrene	<0.004
Dibenz(a,h)anthracene	0.02
252 Group (as Benzo(a)pyrene)	1.26

* Analysis by GC/FID

** Analysis by GC/HECD

*** Analysis by GC/MS-Liquid Crystal

TABLE A.4-7. PHENOL SPECIATION DATA FOR THE PHENOSOLVAN INLET WATER (14.0)

Component (mg/g)	Overall Value*	Retention Time
Phenol	0.69	8.55
o-Cresol (as Phenol)	0.26	9.50
m-Cresol	0.61	9.70
p-Cresol (as Phenol)	0.10	9.90
2,6-Dimethylphenol	0.013	10.10
2,4-Dimethylphenol	0.13	10.50
3,4-Dimethylphenol	0.19	10.95
1-Naphthol	NF	13.20
Unknowns (as Phenol)		
	0.020	10.35
	0.21	10.65
	0.21	11.20
	0.020	11.30
	0.076	11.45
	0.010	11.60
	0.10	11.70
	0.052	12.40
Other Unknowns (as Phenol)**	0.21	–

* Analysis by GC/FID

** Summation of all other unknown peaks

NF = Not found

TABLE A.4-8. ATOMIC ABSORPTION DATA FOR THE PHENOSOLVAN INLET WATER (14.0)

Component (mg/L)	Overall Value
As	0.10
Be	NF
Cd	0.0014
Co	NF
Cr	0.023
Cu	0.011
Hg	0.14
Mo	NF
Ni	0.013
Pb	0.014
Sb	NF
Se	0.050
Sr	0.10
Tl	NF
V	NF
Zn	0.28

NF = Not found

TABLE A.4-9. WATER QUALITY PARAMETERS FOR THE PHENOSOLVAN WASTEWATER (14.11)

Component	Overall Value*	Range
Flow Rate (m^3/gasifier-hr)	-	
Temperature (°C)	33	
pH	9.6	9.0-10.0
Total Solids (mg/L)	1350	960-1520
Total Non-Volatile Solids (mg/L)	54	
Total Suspended Solids (mg/L)	190	28-190
Total Dissolved Solids (mg/L)	1160	880-1490
Water Quality Parameters		
COD (as mgO_2/L)	7910	3130-11130
Permanganate (as mgO_2/L)	4040	4040-28920
BOD_5 (as mgO_2/L)	2350	
True Color (Pt-Co)	13750	
Composition Data (mg/L)		
TOC	1470	
Tars and Oils	<200	
Total Phenols	230	170-270
Volatile Phenols	130	89-160
Other Phenols	100	
Free Ammonia	Tr	
Fixed Ammonia	205	201-209
Cyanide	0.019	0.017-0.02
Nitrites	Tr	
Nitrtes	11.4	10.9-11.85
Pyridines	-	
Chlorides	60	16-122
Florides	Tr	
Sulfites	-	
Sulfates	110	105-112
Hydrogen Sulfide	-	
Thiocyanate	<75	2.8-75
Thiosulfates	Tr	
Sulfur	84	
PO_4^{---}	<2.5	

- = No data available
Tr = Trace
*Values are best values from available data

TABLE A.4-10. POLYNUCLEAR AROMATIC HYDROCARBON DATA FOR THE PHENOSOLVAN WASTEWATER (14.11)

Component (mg/L)	Overall Value*
Benz(a)anthracene	NF
7,12-Dimethylbenz(a)anthracene	NF
Benzo(b)fluoranthrene	NF
Benzo(a)pyrene	NF
3-Methylcholanthrene	NF
Dibenz(a,h)anthracene	NF
252 Group (as Benzo(a)pyrene)	0.19

*Analysis by GC/MS-Liquid Crystal
NF = Not Found

TABLE A.4-11. SPARK SOURCE MASS SPECTRAL DATA FOR THE PHENOSOLVAN WASTEWATER (14.11)

Component (mg/L)	Overall Value
U	≤0.03
Th	≤0.04
Pb	0.07
Ba	0.05
I	0.02
Sn	0.009
Zr	0.02
Y	≤0.03
Sr	0.02
Br	0.009
Se	0.03
As	0.02
Ge	0.03
Zn	0.07
Cu	0.03
Ni	0.08
Co	0.003
Fe	0.5
Mn	0.01
Cr	0.005
V	0.003
Ti	0.02
Sc	≤0.005
Ca	6
K	1
Cl	0.08
P	0.08
Si	1
S	≥10
Al	0.1
Mg	2
Na	4
F	≃0.02
B	0.1
Li	0.003

A5.0. COMPILATION OF DATA FOR SOLID PHASE STREAMS

TABLE A.5-1. TEST DATA FOR SOLID PHASE SAMPLE POINT 1.1, FLEISSNER BAGHOUSE CATCH

Component	Overall Value*	Range
Proximate Analysis (wt %)		
Moisture	24	21-27
Ash	15	13-33
Volatile	35	33-36
Fixed Carbon	27	13-27
Carbon Dioxide	2.9	2.9-14
Total Sulfur	1.0	0.97-1.0
Free Sulfur	0.18	0.17-0.18
Fixed Sulfur	0.82	0.82-0.83
Hydrogen	3.0	2.9-3.1
Nitrogen/Oxygen	15.8	15.3-16.5
Chlorine	-	
Proximate Moisture Free Analysis (wt % dry basis)		
Ash	19	17-42
Volatile	46	42-48
Fixed Carbon	35.0	34.9-35.2
Carbon Dioxide	3.8	3.7-18
Total Sulfur	1.3	
Free Sulfur	0.23	
Fixed Sulfur	1.1	
Hydrogen	4.0	
Nitrogen/Oxygen	21	
Chlorine	-	
Heating Value (Kcal/kg)		
Proximate HHV	3760	3650-3880
LHV	3480	3360-3600
Proximate (Moisture Free)		
HHV	4970	
LHV	4780	

(Continued)

TABLE A.5-1. (Continued)

Component	Overall Value*	Range
Proximate Moisture and Ash Free Analysis (wt %)		
Volatile	57	56-72
Fixed Carbon	43	28-44
Carbon Dioxide	-	
Total Sulfur	1.7	
Free Sulfur	0.29	
Fixed Sulfur	1.4	
Hydrogen	5.0	
Nitrogen/Oxygen	26	
Chlorine	-	
Ash Chemical Composition (wt %)		
SiO_2	25	
Fe_2O_3	6.8	
Al_2O_3	6.7	
CaO	36	
MgO	6.3	
SO_3	16	
P_2O_5	0.34	
TiO_2	0.51	
Na_2O	1.6	
K_2O	0.40	
MnO	0.14	
Acidic/Basic Ratio		
Other Properties		
Specific Gravity (g/ml)	0.57	
Specific Surface area (cm^2/g)	3470	
Tar (wt %)	6.3	
Gas Water (wt %)	9.7	
Semicoke (wt %)	67	
Gas and Losses (wt %)	17	
Grain Size (mm)		-60 to +6

- = No data available

* Values are best values from available data

TABLE A.5-2. TEST DATA FOR SOLID PHASE SAMPLE POINT 2.0, DRIED COAL TO GASIFICATION

Component	Overall Value*	Range
Proximate Analysis (wt %)		
Moisture	24	20-30
Ash	14	20-21
Volatile	36	32-39
Fixed Carbon	27	22-30
Carbon Dioxide	2.3	1.3-3.7
Total Sulfur	1.2	0.89-1.8
Free Sulfur	0.35	0.16-0.84
Fixed Sulfur	0.82	0.64-1.1
Hydrogen	3.4	2.8-3.8
Nitrogen/Oxygen	16.5	15-19
Chlorine	0.01	
Proximate Moisture Free Analysis (wt % dry basis)		
Ash	19	14-27
Volatile	46	35-50
Fixed Carbon	35	23-39
Carbon Dioxide	3.4	1.7-5.2
Total Sulfur	1.5	1.1-2.3
Free Sulfur	0.48	0.21-1.3
Fixed Sulfur	1.1	0.83-1.4
Hydrogen	4.4	3.8-4.8
Nitrogen/Oxygen	22	20-24
Chlorine	0.01	
Heating Value (Kcal/kg)		
Proximate HHV	3900	3210-4340
LHV	3700	2940-4280
Proximate Moisture Free		
HHV	5000	3470-5500
LHV	5050	4040-5500

(Continued)

TABLE A.5-2. (Continued)

Component	Overall Value*	Range
Ultimate Analysis (wt %)		
Moisture	20	
Ash	14	
Volatile	-	
Fixed Carbon	45	
Total Sulfur	0.89	
Free Sulfur	-	
Fixed Sulfur	-	
Hydrogen	3.5	
Nitrogen	1.1	
Oxygen (By Difference)	16	
Chlorine	0.01	
Proximate Moisture and Ash Free Analysis (wt %)		
Volatile	57	54-59
Fixed Carbon	43	41-46
Carbon Dioxide	4.4	2.0-6.8
Total Sulfur	-	
Free Sulfur	0.59	0.26-1.5
Fixed Sulfur	-	
Hydrogen	5.4	4.9-5.9
Nitrogen/Oxygen	27	25-33
Chlorine	-	
Heating Value (Kcal/kg)		
Ultimate HHV	4110	
LHV	-	
Proximate Moisture and Ash Free		
HHV	6200	5860-6390
LHV	6070	5060-6300

(Continued)

TABLE A.5-2. (Continued)

Component	Overall Value*	Range
Ash Fusibility (°C) (Proximate Analysis)		
Sintering Temperature	970	960–1000
Softening Temperature	1180	1130–1220
Hemisphere Temperature	1300	1200–1360
Pouring Temperature	1320	1220–1380
Ash Chemical Composition (wt %) (Ultimate Analysis)		
SiO_2	28	15–40
Fe_2O_3	7.2	4.4–12
Al_2O_3	8.3	2.0–22
CaO	31	20–41
MgO	5.6	0.37–12
SO_3	14	6.5–23
P_2O_5	0.15	Tr–0.34
TiO_2	0.46	0.12–0.92
Na_2O	1.4	0.82–1.8
K_2O	0.32	0.20–0.46
MnO	–	
Acidic/Basic Ratio	0.62	0.37–0.77
Other Properties		
Specific Gravity (g/ml)	0.538	0.5–0.6
Micum Test (+6mm) %	75	70–78
Tar (wt %)	5.6	4.9–6.3
Gas Water (wt %)	11	9.7–12.0
Semicoke (wt %)	67.0	66.9–67.1
Gas and Losses (wt %)	16.5	16.1–16.9

– = No data available

*Values are best values from available data

TABLE A.5-3. PARTICLE SIZE DISTRIBUTION DATA FOR THE DRIED COAL TO GASIFICATION (2.0)

Particle Size (mm)	Cumulative Value (wt %)*	Fraction Value (wt %)*	Fraction Range (wt %)
0 to 1	1.85	1.85	1.1-2.6
1 to 2	2.68	0.83	0.56-1.1
2 to 3	3.6	1.1	0.56-1.6
3 to 6	8.1	4.3	1.1-7.4
5 to 10	9.7	1.6	1.1-2.1
10 to 15	19.5	9.8	7.4-12.2
15 to 20	35.5	16.0	8.4-23.3
20 to 25	45.9	10.4	7.4-13.3
25 to 30	52.4	6.5	6.3-6.7
30 to 40	73.0	20.6	16.8-24.4
40 to 50	80.6	7.6	2.4-7.8
50 to 60	90.7	10.1	4.5-15.8
>60	100.3	9.6	3.3-15.8

*Values are average values of fraction range.

TABLE A.5-4. ATOMIC ABSORPTION DATA FOR THE DRIED COAL TO GASIFICATION (2.0)

Component (mg/kg)	Overall Value
As	59
Be	1.0
Cd	4.0
Co	3.4
Cr	87
Cu	43
Hg	0.74
Mo	6.4
Ni	150
Pb	8.2
Sb	NF
Se	20
Sr	190
Tl	NF
V	14
Zn	140

NF = Not found

TABLE A.5-5. SPARK SOURCE MASS SPECTRAL DATA FOR THE DRIED COAL TO GASIFICATION (2.0)

Component (mg/kg)	Overall Value
U	≤2
Th	≤2
Pb	2
Eu	≤0.3
Sm	1
Nd	0.8
Pr	0.9
Ce	3
La	2
Ba	110
Cs	0.1
I	0.5
Te	0.4
Sn	0.5
Cd	0.4
Mo	6
Nb	3
Zr	6
Y	2
Sr	91
Rb	5
Br	2
Se	0.6
As	2
Ge	0.1
Ga	2
Zn	1
Cu	8
Ni	23
Co	0.4
Mn	230
Cr	11
V	8
Ti	660
Sc	1
Cl	32
P	780
F	≃2
B	21
Li	1

(Continued)

TABLE A.5-5. (Continued)

Component (mg/kg)	Overall Value
Ca	>1000
K	>1000
S	>1000
Si	>1000
Al	>1000
Mg	>1000
Na	>1000
Fe	>1000

TABLE A.5-6. TEST DATA FOR SOLID PHASE SAMPLE POINT 2.1, COAL ROOM DUST

Component	Overall Value*	Range
Proximate Analysis (wt %)		
Moisture	22	21-24
Ash	23	13-33
Volatile	35	33-36
Fixed Carbon	20	13-27
Carbon Dioxide	8.4	2.8-14
Total Sulfur	-	
Free Sulfur	-	
Fixed Sulfur	-	
Hydrogen	-	
Nitrogen	-	
Oxygen	-	
Chlorine	-	
Ash Fusibility (°C)		
Sintering Temperature	1000	
Softening Temperature	1200	1180-1220
Hemisphere Temperature	1300	1230-1360
Pouring Temperature	1320	1250-1380
Ash Chemical Composition (wt %)		
SiO_2	28.8	28.3-29.2
Fe_2O_3	6.8	6.3-7.3
Al_2O_3	7.9	6.2-9.6
CaO	39	38-41
MgO	4.5	4.1-4.8
SO_3	11.0	10.8-11.1
P_2O_5	0.28	0.25-0.30
TiO_2	0.44	0.31-0.56
Na_2O	0.64	0.46-0.82
K_2O	0.39	0.38-0.40
MnO	-	
Acidic/Basic Ratio	0.72	0.67-0.77

(Continued)

TABLE A.5-6. (Continued)

Component	Overall Value*	Range
Other Properties		
Specific Gravity (g/ml)	0.57	
Micum Test (+6mm) %	-	
Tar (wt %)	-	
Gas Water (wt %)	-	
Semicoke (wt %)	-	
Gas and Losses (wt %)	-	
Grain Size (mm)	-	
Specific Surface Area (cm^2/g)	3500	

- = No data available
*Values are best values from available data

TABLE A.5-7. PARTICLE SIZE DISTRIBUTION DATA FOR THE COAL ROOM DUST (2.1)

Particle Size (microns)	Cumulative Value (wt %)	Fraction Value (wt %)
0 to 63	33.4	33.4
63 to 125	55	21.2
125 to 200	65	10.4
200 to 500	100	35.0

TABLE A.5-8. SPARK SOURCE MASS SPECTRAL DATA FOR THE COAL ROOM DUST (2.1)

Component (mg/kg)	Overall Value
Ba	370
Mn	170
Cr	15
Ni	9
V	16
Cu	3
Co	8
Sr	83
Ti	400
Cd	0.3

TABLE A.5-9. TEST DATA FOR SOLID PHASE SAMPLE POINT 12.1, DRY GASIFIER ASH

Component	Overall Value
Proximate Analysis (wt %)	
Moisture	2.1
Ash	94
Volatile	6.5
Fixed Carbon	-
Coke	-
Combustibles	-
Total Carbon	-
Carbon Dioxide	-
Total Sulfur	0.15
Free Sulfur	-
Fixed Sulfur	-
Hydrogen	-
Nitrogen	-
Oxygen	-
Chlorine	-
Proximate Moisture Free Analysis (wt % dry basis)	
Ash	95
Volatile	6.7
Fixed Carbon	-
Coke	-
Combustibles	-
Total Carbon	-
Carbon Dioxide	-
Total Sulfur	0.15
Free Sulfur	-
Fixed Sulfur	-
Hydrogen	-
Nitrogen	-
Oxygen	-
Chlorine	-
Heating Value (Kcal/kg)	
Proximate HHV	27.8
LHV	-
Proximate Moisture Free	
HHV	28.3
LHV	-

(Continued)

TABLE A.5-9. (Continued)

Component	Overall Value
Ultimate Analysis (wt %)	
Moisture	2.1
Ash	94
Volatile	-
Fixed Carbon	1.7
Carbon Dioxide	-
Total Sulfur	0.15
Free Sulfur	-
Fixed Sulfur	-
Hydrogen	0.25
Nitrogen	0.03
Oxygen (By Difference)	2.3
Chlorine	0.04
Ultimate Moisture Free Analysis (wt % dry basis)	
Ash	95
Volatile	-
Fixed Carbon	1.8
Carbon Dioxide	-
Total Sulfur	0.15
Free Sulfur	-
Fixed Sulfur	-
Hydrogen	0.26
Nitrogen	0.03
Oxygen (By Difference)	2.3
Chlorine	0.04

- = No data available

TABLE A.5-10. ATOMIC ABSORPTION DATA FOR THE DRY GASIFIER ASH (12.1)

Component (mg/kg)	Overall Value
As	75
Be	2.5
Cd	69
Co	17
Cr	180
Cu	40
Hg	0.30
Mo	8.9
Ni	320
Pb	52
Sb	NF
Se	24
Sr	370
Tl	NF
V	100
Zn	2.1

NF = Not found

TABLE A.5-11. SPARK SOURCE MASS SPECTRAL DATA FOR THE DRY GASIFIER ASH (12.1)

Component (mg/kg)	Overall Value
B	190
Ba	>1000
Be	4
Mn	>1000
Sb	2
Pb	9
Cr	2
Ga	17
Ni	180
Mo	6
Sn	0.8
V	67
Cu	27
Y	17
Zn	33
Zr	33
Co	4
Sr	320
Ti	>1000
Ge	0.5
La	21
As	62
U	2
Th	9
Er	0.5
Ho	0.6
Dy	2
Tb	0.4
Gd	2
Eu	1
Sm	9
Nd	10
Pr	5
Ce	29
Cs	3
I	2
Te	≤1
Nb	10
Rb	35
Sc	12
Cl	45

(Continued)

TABLE A.5-11. (Continued)

Component (mg/kg)	Overall Value
S	420
F	710
Li	28
Br	17
Se	≤ 1
Ca	>1000
K	>1000
P	>1000
Si	>1000
Al	>1000
Mg	>1000
Na	>1000
Fe	>1000

TABLE A.5-12. TEST DATA FOR SOLID PHASE SAMPLE POINT 12.2, WET GASIFIER ASH

Component	Overall Value*	Range
Proximate Analysis (wt %)		
Moisture	34	29–37
Ash	59	55–63
Volatile	6.0	4.6–7.2
Fixed Carbon	1.3	0.7–2.5
Carbon Dioxide	5.7	4.6–6.5
Total Sulfur	0.09	0.07–0.12
Free Sulfur	0.02	0.01–0.04
Fixed Sulfur	0.07	0.06–0.08
Hydrogen	0.38	0.36–0.40
Nitrogen/Oxygen	4.2	3.7–4.7
Chlorine	–	
Proximate Moisture Free Analysis (wt % dry basis)		
Ash	89	87–91
Volatile	9.1	7.3–11
Fixed Carbon	1.9	1.1–3.5
Carbon Dioxide	8.8	7.3–10
Total Sulfur	0.13	0.10–0.18
Free Sulfur	0.03	0.01–0.06
Fixed Sulfur	0.10	0.09–0.12
Hydrogen	0.58	0.57–0.61
Nitrogen/Oxygen	6.5	5.9–6.9
Chlorine	–	

(Continued)

TABLE A.5-12. (Continued)

Component	Overall Value*	Range
Proximate Moisture and Ash Free Analysis (wt %)		
Volatile	81	74-88
Fixed Carbon	19	12-26.0
Carbon Dioxide	-	
Total Sulfur	-	
Free Sulfur	-	
Fixed Sulfur	-	
Hydrogen	-	
Nitrogen/Oxygen	-	
Chlorine	-	
Ash Fusibility (°C)		
Sintering Temperature	1120	1100-1130
Softening Temperature	1220	1180-1280
Hemisphere Temperature	1240	1190-1290
Pouring Temperature	1250	1200-1300
Ash Chemical Composition (wt %)		
SiO_2	30	25-36
Fe_2O_3	6.6	3.9-11.0
Al_2O_3	6.6	4.1-11.0
CaO	38	29-43
MgO	6.7	5.1-7.4
SO_3	3.4	0.36-5.8
P_2O_5	0.29	0.28-0.29
TiO_2	0.42	0.27-0.49
Na_2O	1.4	1.1-1.8
K_2O	0.57	0.38-0.76
MnO	0.10	
Acidic/Basic Ratio	0.65	0.59-0.71

- = No data available

*Values are best values from available data

TABLE A.5-13. SPARK SOURCE MASS SPECTRAL DATA FOR THE WET GASIFIER ASH (12.1)

Component (mg/kg)	Overall Value*	Range
B	630	
Ba	1670	
Be	NF	
Bi	NF	
Mn	2700	1200-2700
Sb	NF	NF-2
Pb	27	24-29
Cr	240	90-240
Ga	37	
Ni	180	
Mo	30	
Sn	NF	
V	140	
Cu	76	48-76
Ag	NF	
Y	39	
Zn	56	
Zr	180	
Co	15	
Sr	4100	
Ti	2300	
Sc	20	
La	NF	
Cd	1.2	

NF = Not found

* Values are best values from available data

TABLE A.5-14. TEST DATA FOR SOLID PHASE SAMPLE POINT 13.8, HEAVY TAR

Component	Overall Value
Ultimate Moisture Free Analysis (wt % dry basis)	
Ash	6.6
Volatile	-
Fixed Carbon	-
Total Sulfur	0.33
Free Sulfur	-
Fixed Sulfur	-
Hydrogen	7.6
Nitrogen	0.87
Oxygen (By Difference)	28.6
Chlorine	-
Heating Value (Kcal/kg)	
Ultimate HHV	6340
LHV	-
Insoluble Particulates	26

- = No data available

TABLE A.5-15. POLYNUCLEAR AROMATIC DATA FOR THE HEAVY TAR (13.8)

Component (mg/kg)	Overall Value
Benz(a)anthracene	500
7,12-Dimethylbenz(a)anthracene	1300
Benzo(b)fluoranthrene	320
Benzo(a)pyrene	240
3-Methylcholanthrene	NF
Dibenz(a,h)anthracene	14
252 Group (as Benzo(a)pyrene)	1000

NF = Not found

TABLE A.5-16. PHENOL SPECIATION DATA FOR THE HEAVY TAR (13.8)

Component (mg/g)	Overall Value*	Retention Time
Phenol	3.3	8.55
o-Cresol (as Phenol)	2.4	9.50
m-Cresol	6.7	9.70
p-Cresol (as Phenol)	0.70	9.90
2,6-Dimethylphenol	0.57	10.10
2,4-Dimethylphenol	3.6	10.50
3,4-Dimethylphenol	2.0	10.95
1-Naphthol	0.69	13.20
Unknowns (as Phenol)		
	0.61	10.35
	5.4	10.65
	0.98	11.20
	1.7	11.30
	1.9	11.45
	1.4	11.60
	1.8	11.70
	1.2	12.35
	1.2	12.40
Other Unknowns (as Phenol)**	81	-

* Analysis by GC/FID

** Summation of all other unknown peaks

TABLE A.5-17. ATOMIC ABSORPTION DATA FOR THE HEAVY TAR (13.8)

Component (mg/kg)	Overall Value
As	16
Be	0.29
Cd	3.7
Co	1.5
Cr	30
Cu	6.0
Hg	0.64
Mo	0.85
Ni	21
Pb	64
Sb	3.9
Se	2.6
Sr	41
Tl	NF
V	5.7
Zn	98

NF = Not found

A6.0. LEACHATE TEST RESULTS FOR KOSOVO GASIFIER ASH

TABLE A.6-1. SPARK SOURCE MASS SPECTRAL DATA FOR THE RCRA LEACHATE (ACID LEACHATE) OF THE DRY GASIFIER ASH (12.1)

Component (mg/L)	Overall Value
U	≤0.007
Th	≤0.008
Pb	0.008
Ba	3
Cs	0.004
Sb	≤0.002
Sn	≤0.001
Mo	0.1
Zr	≤0.006
Y	0.008
Sr	4
Rb	0.04
Br	≤0.008
Se	0.01
As	≤0.004
Ge	≤0.001
Zn	0.05
Cu	0.01
Ni	0.04
Co	≤0.001
Fe	10
Mn	0.001
Cr	0.3
V	0.07
Ti	0.01
Sc	≤0.001
Cl	0.05
S	>6
P	0.02
Si	8
Al	0.01
Mg	2
Na	>2
F	≃0.8
Li	0.03
B	0.09

TABLE A.6-2. SPARK SOURCE MASS SPECTRAL DATA FOR THE ASTM LEACHATE (NEUTRAL LEACHATE) OF THE DRY GASIFIER ASH (12.1)

Component (mg/L)	Overall Value
U	≤0.03
Th	≤0.04
Pb	0.07
Ba	0.05
I	0.005
Mo	0.05
Nb	0.006
Sr	0.3
Rb	0.09
Br	0.4
Se	0.007
As	0.01
Ge	0.01
Ga	0.02
Zn	0.08
Cu	0.03
Ni	0.02
Co	≤0.007
Fe	0.1
Mn	0.02
Cr	0.5
V	0.004
Ti	0.02
Sc	≤0.003
Cl	0.7
P	0.2
Si	7
Al	2
F	≃7
B	0.1
Li	0.07

A7.0. HEADSPACE ANALYSES FOR KOSOVO BY-PRODUCTS AND HEAVY TAR

TABLE A.7-1. HEADSPACE RESULTS FOR HEAVY TAR AND LIQUID BY-PRODUCTS

Component	15.3 Naphtha	13.10 Medium Oil	13.9 Light Tar	13.8 Heavy Tar	14.16 Crude Phenol
Ambient Conditions ($\mu g \times 10^6/m^3$)					
Benzene	72	7.4	0.77	–	–
Toluene	10	4.2	0.60	–	NF
Ethylbenzene	0.31	0.34	–	–	–
Xylenes-m,p	0.96	1.6	–	–	–
Xylenes-o	0.74	1.0	–	–	–
At 65°C ($\mu g \times 10^6/m^3$)					
Benzene	5900	25	3.0	1.3	–
Toluene	1300	22	3.1	1.0	–
Ethylbenzene	51	3.1	–	–	–
Xylenes-m,p	130	11	1.0	–	–
Xylenes-o	87	8.0	–	–	–
H_2S	Tr	Tr	NF	NF	NF
COS	NF	Tr	Tr	NF	NF
CH_3SH	0.38	0.019	Tr	0.0064	Tr
C_2H_5SH	170	1.4	0.035	0.05	0.0028
Unknowns (as C_2H_5SH)					
Retention Time					
14.4	0.43	0.033	0.041	NF	0.069
15.7	5.6	0.091	NF	NF	0.033
18.2	27	0.99	NF	NF	NF
20.6	6.4	0.35	NF	NF	NF
41.2	1.9	0.35	NF	NF	NF

Tr = Trace, ~1 ppmv
NF = Not found, less than 1 ppmv
– = No data available

A8.0. COMPILATION OF DATA FOR KOSOVO BY-PRODUCTS

TABLE A.8-1. TEST DATA FOR BY-PRODUCT SAMPLE POINT 13.9, LIGHT TAR

Component	Overall Value	Range
Specific Gravity (g/cm^3)	1.06	
High Heating Value (kcal/Kg)	8910	8710-9810
Low Heating Value (kcal/Kg)	8280	
Ultimate Analysis (wt %)		
Carbon	82	72-82
Hydrogen	8.4	8.1-8.4
Nitrogen	1.3	
Sulfur	0.49	0.49-0.75
Ash	0.22	0.22-0.92
Chlorine	–	
Oxygen (Difference)	7.8	
Moisture	1.1	

– = No data available

*Values are best values from available data

TABLE A.8-2. POLYNUCLEAR AROMATIC HYDROCARBON DATA FOR THE LIGHT TAR (13.9)

Component (mg/kg)	Overall Value*
Benz(a)anthracene	490
7,12-Dimethylbenz(a)anthracene	1100
Benzo(b)fluoranthrene	310
Benzo(a)pyrene	210
3-Methylchloanthrene	26
Dibenz(a,h)anthracene	23
252 Group (as Benzo(a)pyrene)	950

*Analysis by GC/MS-Liquid Crystal

TABLE A.8-3. PHENOL SPECIATION DATA FOR THE LIGHT TAR (13.9)

Component (mg/g)	Overall Value*	Retention Time
Phenol	5.9	8.55
o-Cresol (as Phenol)	4.9	9.50
m-Cresol	13	9.70
p-Cresol (as Phenol)	1.4	9.90
2,6-Dimethylphenol	1.2	10.10
3,4-Dimethylphenol	7.5	10.50
3,4-Dimethylphenol	3.9	10.95
1-Naphthol	1.0	13.20
Unknowns (as Phenol)		
	1.3	10.35
	10.1	10.65
	2.1	11.20
	3.7	11.30
	3.3	11.45
	2.8	11.60
	4.3	11.70
	2.6	12.35
	2.7	12.40
Other Unknowns (as Phenol)**	94	-

* Analysis by GC/FID

** Summation of all other unknown peaks

TABLE A.8-4. ATOMIC ABSORPTION DATA FOR THE LIGHT TAR (13.9)

Component (mg/L)	Overall Value
Trace Elements (mg/1) by AA	
As	18
Be	0.10
Cd	0.70
Co	NF
Cr	3.2
Cu	17
Hg	NF
Mo	NF
Ni	9.5
Pb	7.2
Sb	NF
Se	1.7
Sr	21
Tl	0.42
V	0.53
Zn	30

NF = Not found

TABLE A.8-5. TEST DATA FOR BY-PRODUCT SAMPLE POINT 13.10, MEDIUM OIL

Component	Overall Value*	Range
Specific Gravity (g/cm^3)	0.97	
High Heating Value (kcal/Kg)	9500	9100-9900
Low Heating Value (kcal/Kg)	9400	
Ultimate Analysis (wt %)		
Carbon	81.8	81.1-82.4
Hydrogen	8.94	8.91-8.96
Nitrogen	1.00	–
Sulfur	0.83	0.7-0.95
Ash	0.03	
Chlorine	–	
Oxygen (Difference)	8.2	
Moisture	0.8	

– = No data available

* Values are best values from available data

TABLE A.8-6. POLYNUCLEAR AROMATIC HYDROCARBON DATA FOR THE MEDIUM OIL (13.10)

Component (mg/kg)	Overall Value
Benz(a)anthracene	160
7,12-Dimethylbenz(a)anthracene	62
Benzo(b)fluoranthrene	120
Benzo(a)pyrene	68
3-Methylcholanthrene	NF
Dibenz(a,h)anthracene	6.6
252 Group (as Benzo(a)pyrene)	280

NF = Not Found

TABLE A.8-7. PHENOL SPECIATION DATA FOR THE MEDIUM OIL (13.10)

Component (mg/g)	Overall Value*	Retention Time
Phenol	19	8.55
o-Cresol (as Phenol)	19	9.50
m-Cresol	38	9.70
p-Cresol (as Phenol)	5.1	9.90
2,6-Dimethylphenol	4.6	10.10
3,4-Dimethylphenol	22	10.50
3,4-Dimethylphenol	12	10.95
1-Naphthol	0.73	13.20
Unknowns (as Phenol)		
	4.0	10.35
	22	10.65
	4.7	11.20
	8.3	11.30
	6.0	11.45
	5.0	11.60
	9.2	11.70
	3.4	12.35
	6.1	12.40
Other Unknowns (as Phenol)**	42	-

* Analysis by GC/FID

** Summation of all other unknown peaks

TABLE A.8-8. ATOMIC ABSORPTION DATA FOR THE MEDIUM OIL (13.10)

Component	Overall Value
As	1.9
Be	NF
Cd	0.075
Co	0.19
Cr	3.9
Cu	1.1
Hg	0.20
Mo	0.18
Ni	NF
Pb	1.4
Sb	NF
Se	1.8
Sr	8.3
Tl	NF
V	NF
Zn	15

NF = Not found

TABLE A.8-9. SPARK SOURCE MASS SPECTRAL DATA FOR THE MEDIUM OIL (13.10)

Component (mg/L)	Overall Value
U	0.07
Th	≤0.02
Bi	0.01
Pb	0.09
Ce	0.003
Ln	≤0.004
Ba	0.09
Sn	0.008
Cd	0.01
Mo	0.005
Zr	≤0.003
Y	0.003
Sr	0.008
Se	0.02
As	0.4
Zn	0.3
Cu	0.5
Ni	0.03
Co	0.004
Fe	2
Mn	0.02
Cr	0.02
V	0.01
Ti	0.09
Sc	≤0.001
Ca	5
K	0.3
Cl	0.008
S	0.6
P	0.1
Si	2
Al	0.09
Na	0.1
F	≃0.03
B	0.07
Li	0.001
Mg	>10

TABLE A.8-10. TEST DATA FOR BY-PRODUCT SAMPLE POINT 15.3, NAPHTHA

Component	Overall Value*	Range
Specific Gravity (g/cm^3)	0.845	
High Heating Value (kcal/Kg)	9940	9390-9940
Low Heating Value (kcal/Kg)	8930	
Ultimate Analysis (wt %)		
Carbon	86	78-86
Hydrogen	9.9	8.7-9.9
Nitrogen	0.18	
Sulfur	2.2	1.4-2.2
Ash	–	
Chlorine	–	
Oxygen (Difference)	2.2	

– = No data available
* Values are best values from available data

TABLE A.8-11. POLYNUCLEAR AROMATIC HYDROCARBON DATA FOR THE NAPTHA (15.3)

Component	Overall Value*
Benz(a)anthracene	NF
7,12-Dimethylbenz(a)anthracene	NF
Benzo(b)fluoranthrene	NF
Benzo(a)pyrene	NF
3-Methylcholanthrene	NF
Dibenz(a,h)anthracene	NF
252 Group (as Benzo(a)pyrene)	NF

NF = Not found
* Analaysis by GC/MS-Liquid Crystal

TABLE A.8-12. ATOMIC ABSORPTION DATA FOR THE NAPHTHA (15.3)

Component (mg/L)	Overall Value
As	0.55
Be	0.0018
Cd	0.0008
Co	0.005
Cr	0.10
Cu	0.15
Hg	0.13
Mo	0.009
Ni	0.14
Pb	0.064
Sb	0.012
Se	0.73
Sr	NF
Tl	NF
V	NF
Zn	0.14

NF = Not found

TABLE A.8-13. TEST DATA FOR BY-PRODUCT SAMPLE POINT 14.16, CRUDE PHENOL

Component	Overall Value
Specific Gravity (g/cm^3)	-
High Heating Value (kcal/Kg)	-
Low Heating Value (kcal/Kg)	7790
Ultimate Analysis (wt %)	
Carbon	-
Hydrogen	-
Nitrogen	-
Sulfur	-
Ash	-
Chlorine	-
Oxygen (Difference)	-

- = No data available

APPENDIX B
BIOASSAY RESULTS

LEVEL 1 EPA HEALTH EFFECTS TESTS ON COAL GASIFICATION SAMPLES

Final Report

to

RADIAN CORPORATION

P. O. Box 9948

Austin, TX 78766

ADL Reference 84625

Subcontract under EPA Prime Contract 68-02-2147

(Task 1, Sub-Task 25)

June 30, 1980

This report is reprinted as received from Arthur D. Little, Inc. Therefore, the format is not consistent with EPA requirements.

Arthur D. Little, Inc.

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I. INTRODUCTION

Arthur D. Little, Inc., conducted Level 1 EPA Health Effects Tests on coal gasification process samples for the Radian Corporation. Samples were received on March 21, 1980.

The Test Matrix conducted is given below.

Test Matrix

		Bioassay			
Sample No.	Description	Ames	CHO	RAM	Rodent
2468	Slag	✓		✓	✓
1152A*	Light Oil	✓	✓		✓
2471*	Medium Oil	✓	✓		✓
2472*	Tar	✓	✓		✓
2473*	Heavy Tar and Dust	✓	✓		✓
2987	Wastewater COD = 17,700 mg/l	✓	✓		✓
2988	Treated Wastewater COD = 5,540 mg/l	✓	✓		✓
2468L	ASTM Slag Leachate	✓	✓		✓
2473L	ASTM Heavy Tar Leachate	✓	✓		✓

---

* Samples extracted with 9 parts methylene chloride and solvent-exchanged with an equal volume of dimethylsulfoxide (DMSO) before application to all *in vitro* tests. See Section III.

II. SUMMARY OF RESULTS

Sample No.	Ames*	In Vitro Cytotoxicity** IC_{50}[†]	Rodent[††] Test/Control
2468	Negative	>1000	1/2
1152A	Negative	0.68	7/2
2471	Negative	0.11	10/2
2472	Positive	0.03	7/2
2473	Positive	0.07	3/1
2987	Positive	37	1/2
2988	Negative	98	0/2
2468L	Negative	>600	1/0
2473L	Negative	120	3/0

---

* Highest concentration tested varied depending on sample toxicity. See Section IV.

** All samples tested in CHO assay except sample 2468 which was tested in the RAM assay.

[†] EC_{50}'s given in µl/ml or µg/ml.

[††] Number of dead mice in test group over control group. Ten animals were used in each group. See details in Section V.

III. SAMPLES REQUIRING SPECIAL HANDLING

Samples 1152A, 2471, 2472 and 2473 were organic liquid/solids marked as particularly volatile and hazardous. Instructions for handling them included that they should not come in contact with the skin. The use of a respirator and a hood were strongly recommended. Vapors from 1152A were reported to cause a severe headache (letter dated March 20, 1980, from R. V. Collins, Radian Corporation).

An extraction and solvent exchange procedure to prepare these samples for in vitro bioassays was designed in collaboration with Dr. Collins. The original samples were immiscible with water and contained extremely volatile components.

Protocol for Extraction and Solvent Exchange

Sample
(4.0 ml or 4.0 gm)

↓

Add 36 ml CH_2Cl_2

↓

Shake several hours at room temperature

↓

Shake 1 part CH_2Cl_2 phase with 1 part DMSO

↓

CH_2Cl_2 was removed under a stream
of nitrogen gas below 40°C for 7 hours

↓

DMSO was added to bring final volume
to 40 ml

↓

Original sample now diluted 1:10 in DMSO.
Additional serial dilutions were prepared
in DMSO as described in Sections IV and V.

IV. SALMONELLA MUTAGENESIS ASSAY (AMES)

Test Samples:

2988
2468L
2468
2987
2473L

2471
2472
2473
1152A

SUMMARY

The above samples were tested in the plate incorporation assay of Ames against *Salmonella typhimurium* strains TA-98, TA-100, TA-1535, TA-1537 and TA-1538 with and without metabolic activation. The solid sample was tested at four log concentrations, the highest concentration being 1.0 mg/plate. Liquids were tested at concentrations of 250, 200, 150 and 100 µl/plate unless the consistency (i.e., sample 2473L, ASTM Heavy Tar Leachate) or toxicity (i.e., samples 1152A, 2471, 2472 and 2473) did not permit this. The highest concentration of sample 2473L which could be incorporated in the agar plate was 150 µl/plate. The very volatile and toxic samples 1152A, 2471, 2472 and 2473 were tested at concentrations of 0.025, 0.02, 0.015 and 0.01 µl/plate after they had been extracted with methylene chloride and solvent-exchanged with DMSO.

MATERIALS

Test materials are described in Section I. Methylene chloride extraction and DMSO exchange of samples 1152A, 2471, 2472 and 2473 are described in Section II.

METHODS

The *Salmonella typhimurium* strains TA-98, TA-100, TA-1535, TA-1537 and TA-1538 used in this study were obtained from Dr. Bruce Ames. The protocol for the assay was as described in the IERL-RTP Procedures Manual, Level 1, EPA 600/6-77-04, April, 1977. The assay is conducted in a culture medium which contains insufficient histidine to allow the tester strains to proliferate sufficiently to give colonies. After incubation for 48 hours at 37°C, the mutant colonies (formed by his^+ revertants) are counted. Results are reported as total number of revertants per plate. Briefly, in this assay the test organisms, with or without microsomal preparations (S-9) and test material, were mixed in the molten top agar and poured on duplicate plates at four concentrations.

Solid sample 2468 was tested at four log concentrations, the highest concentration being 1.0 mg/plate. Liquids 2988 and 2468L were tested at 250, 200, 150 and 100 µl/plate. Samples 2473L (Heavy Tar Leachate) and 2987 (Wastewater) were tested at 150, 100, 50 and 25 µl/plate because of either viscosity (2473L) or toxicity (2987). The very volatile samples 1152A, 2471, 2472 and 2473 were extracted with methylene chloride and solvent-exchanged with DMSO (Section II) and tested at concentrations of 0.025, 0.02, 0.015 and 0.01 µl/plate. Each set of plates for each concentration of each of these four volatile samples was placed in a Ziploc bag before being placed in an incubator for the 48-hour incubation period. Corresponding positive and negative controls for these assays were handled in the same manner.

Controls which were included in every experiment consisted of negative controls for the spontaneous reversion rate for each tester strain, and the positive controls listed below, compounds which do and do not require metabolic activation.

Tester Strain	Positive Control Chemicals
All Strains	2-Anthramine, 10 µg/plate
TA-98	Daunomycin, 10 µg/plate
TA-100	Methylmethane sulfonate, 50 µg/plate
TA-1535	N-methyl-N'-nitro-N-nitrosoguanidine, 50 µg/plate
TA-1537	9-Aminoacridine, 50 µg/plate
TA-1538	2-Nitrofluorene, 10 µg/plate

For all experiments reported in this study, the following sterility controls (inoculated on Nutrient Agar plates) were negative: solvent, sample, S-9 mix and histidine/biotin supplement. Uninoculated media controls, which were also negative, included Minimal Glucose Agar, Nutrient Agar and Nutrient Broth.

All nine samples were tested in four experiments conducted on separate days.

RESULTS

The results are summarized in Table IV-1 and individually presented in Tables IV-2 through IV-5.

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TABLE IV-1

SUMMARY OF RESULTS OF AMES ASSAY

2468 - Slag

There was no mutagenic activity for any of the strains with or without metabolic activation at concentrations up to 1 mg/plate. Some toxicity was evident at the highest concentration tested with all strains and at 0.1 mg/plate with strains TA-1537, TA-100 and TA-1535.

2987 - Wastewater

There was a positive response with TA-98 and TA-1538 with metabolic activation at 100 μl/plate. There was toxicity for TA-98, TA-1538 and TA-1535 at the highest concentration tested (150 μl/plate).

2988 - Treated Wastewater

There was no mutagenic activity and no toxicity at concentrations up to 250 μl/plate.

2468L - ASTM Slag Leachate

There was no mutagenic activity and no toxicity at concentrations up to 250 μl/plate.

2473L - ASTM Heavy Tar Leachate

There was no mutagenic activity and no toxicity at concentrations up to 150 μl/plate.

TABLE IV-1

SUMMARY OF RESULTS OF AMES ASSAY

(continued)

2471 - Medium Oil (Solvent-Exchanged with DMSO)*

There was no mutagenic activity at concentrations up to 0.025 μl/plate. There was slight toxicity for TA-1537 and TA-100 at 0.025 μl/plate.

2472 - Tar (Solvent-Exchanged with DMSO)*

There was a positive response with TA-1538 at 0.02 μl/plate without metabolic activation and beginning with 0.01 μl/plate (the lowest concentration tested) with metabolic activation. There was also a positive response with TA-98 with metabolic activation beginning with 0.015 ul/plate. The highest concentration tested (0.025 μl/plate) caused a slight toxic effect to the lawn of all the strains.

2473 - Heavy Tar and Dust (Solvent-Exchanged with DMSO)*

There was a positive response with TA-98 with metabolic activation at 0.02 μl/plate and with TA-1538 with metabolic activation at 0.01 μl/plate.

1152A - Light Oil (Solvent-Exchanged with DMSO)*

There was no mutagenic activity for any of the strains with or without metabolic activation at concentrations up to 0.025 μl/plate. There was overall slight toxicity at all concentrations tested.

TABLE IV-1

SUMMARY OF RESULTS OF AMES ASSAY

(continued)

Footnote:

* Volatile samples 2471, 2472, 2473 and 1152A were solvent-exchanged with DMSO. Solvent-exchanged samples contained highly volatile components and were tested in the Ames assay under special handling conditions. Each set of plates for each concentration tested was placed in a Ziploc bag before being placed in an incubator for the 48-hour incubation period. Corresponding positive and negative controls for these assays were handled in the same manner. All four volatile, solvent-exchanged samples showed overall slight toxicity at all concentrations and for all strains. Bacterial colonies in all plates which are held in plastic bags (including those in control dishes) are smaller than normal due perhaps to the lack of oxygen under such assay conditions. Additionally, colonies in dishes treated with volatile samples were smaller than their corresponding controls. Strain TA-100, treated with all four samples in the presence of metabolic activation, gave abnormal spreading colonies indicative of cell membrane disruption.

TABLE IV-2

AMES ASSAY I

SAMPLE #2988 - TREATED WASTEWATER

SAMPLE #2468L - ASTM SLAG LEACHATE

	Revertants Per Plate*									
	TA-98		TA-1537		TA-1538		TA-100		TA-1535	
	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9
Control (DMSO)	19 ± 1	24 ± 2	7 ± 0	9 ± 1	16 ± 0	17 ± 2	93 ± 4	105 ± 1	14 ± 4	14 ± 3
2-Anthramine** (10 μg/plate)	18 ± 1	224 ± 21	11 ± 2	43 ± 4	18 ± 2	95 ± 11	88 ± 2	358 ± 2	17 ± 3	34 ± 1
Daunomycin*** (10 μg/plate)	845 ± 5	683 ± 63								
9-Aminoacridine† (50 μg/plate)			24 ± 2	29 ± 5						
2-Nitrofluorene** (10 μg/plate)					94 ± 15	57 ± 2				
Methylmethane sulfonate** (50 μg/plate)							192 ± 8	162 ± 8		
N-Methyl-N'-nitro-N-nitrosoguanidine ** (50 μg/plate)									2449 ± 192	1970 ± 130
#2988 - Treated Wastewater***										
(100 μl/plate)	22 ± 4	25 ± 2	11 ± 0	7 ± 0	11 ± 2	20 ± 2	94 ± 4	96 ± 4	13 ± 3	17 ± 3
(150 μl/plate)	18 ± 3	23 ± 3	9 ± 0	12 ± 0	18 ± 3	30 ± 2	81 ± 10	91 ± 6	11 ± 2	13 ± 1
(200 μl/plate)	21 ± 6	34 ± 2	8 ± 1	7 ± 1	10 ± 3	21 ± 4	89 ± 0	100 ± 6	12 ± 6	10 ± 2
(250 μl/plate)	20 ± 3	35 ± 2	8 ± 5	11 ± 2	12 ± 1	23 ± 2	85 ± 10	99 ± 7	18 ± 0	15 ± 2
#2468L - ASTM Slag Leachate***										
(100 μl/plate)	17 ± 4	25 ± 1	4 ± 2	6 ± 1	11 ± 2	17 ± 5	104 ± 1	95 ± 12	17 ± 2	14 ± 1
(150 μl/plate)	17 ± 1	20 ± 1	5 ± 1	8 ± 3	10 ± 3	13 ± 3	99 ± 2	97 ± 4	18 ± 8	14 ± 0
(200 μl/plate)	21 ± 5	19 ± 2	4 ± 1	9 ± 4	14 ± 4	22 ± 2	90 ± 1	103 ± 1	16 ± 3	16 ± 2
(250 μl/plate)	19 ± 3	29 ± 7	7 ± 2	8 ± 3	12 ± 2	18 ± 3	97 ± 1	99 ± 3	18 ± 1	16 ± 1

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* Mean of 2 replicate plates ± standard error of the mean.
** Dissolved and/or suspended in dimethylsulfoxide (DMSO).
*** Dissolved and/or suspended in sterile distilled water.
† Dissolved in 95% ethanol.

TABLE IV-3

AMES ASSAY II

SAMPLE #2468 - SLAG

SAMPLE #2987 - WASTEWATER

SAMPLE #2473L - ASTM HEAVY TAR LEACHATE

	Revertants Per Plate*									
	TA-98		TA-1537		TA-1538		TA-100		TA-1535	
	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9
Control (DMSO)	24 ± 4	26 ± 4	6 ± 0	8 ± 1	15 ± 1	17 ± 0	116 ± 2	121 ± 1	14 ± 3	15 ± 4
2-Anthramine** (10 µg/plate)	27 ± 0	>500	9 ± 2	149 ± 16	13 ± 1	>500	136 ± 1	>500	15 ± 1	112 ± 16
Daunomycin*** (10 µg/plate)	>500	>500								
9-Aminoacridine† (50 µg/plate)			152 ± 4	195 ± 3						
2-Nitrofluorene** (10 µg/plate)					>500	>500				
Methylmethane sulfonate** (50 µg/plate)							>500	119 ± 2		
N-Methyl-N'-nitro-N-nitrosoguanidine** (50 µg/plate)									TNTC††	TNTC
#2468 - Slag**										
(0.001 mg/plate)	18 ± 1	19 ± 1	5 ± 1	7 ± 1	13 ± 2	10 ± 2	107 ± 4	104 ± 11	16 ± 2	11 ± 1
(0.01 mg/plate)	24 ± 1	19 ± 1	8 ± 1	5 ± 0	11 ± 1	12 ± 4	123 ± 4	111 ± 2	13 ± 3	9 ± 3
(0.1 mg/plate)	21 ± 1	21 ± 1	3 ± 1	4 ± 1	14 ± 5	14 ± 0	96 ± 2	86 ± 4	13 ± 0	9 ± 3
(1.0 mg/plate)	20 ± 2	14 ± 0	2 ± 1	4 ± 1	5 ± 1	8 ± 1	103 ± 4	86 ± 1	9 ± 2	7 ± 1
#2987 - Wastewater**										
(25 µl/plate)	15 ± 3	27 ± 5	7 ± 0	4 ± 1	10 ± 0	18 ± 2	90 ± 2	89 ± 7	12 ± 2	10 ± 1
(50 µl/plate)	22 ± 3	45 ± 4	6 ± 1	8 ± 1	10 ± 1	21 ± 5	86 ± 2	85 ± 11	13 ± 0	7 ± 1
(100 µl/plate)	18 ± 1	60 ± 2	5 ± 0	6 ± 1	7 ± 1	35 ± 3	107 ± 5	97 ± 4	13 ± 3	7 ± 1
(150 µl/plate)	13 ± 2	40 ± 1	3 ± 1	11 ± 2	5 ± 1	47 ± 1	105 ± 5	109 ± 1	7 ± 1	5 ± 2
#2473L - ASTM Heavy Tar Leachate**										
(25 µl/plate)	16 ± 0	22 ± 4	5 ± 0	6 ± 1	9 ± 3	13 ± 2	111 ± 2	114 ± 4	12 ± 1	11 ± 1
(50 µl/plate)	18 ± 0	24 ± 3	8 ± 3	8 ± 0	6 ± 1	17 ± 2	97 ± 0	82 ± 17	16 ± 5	7 ± 2
(100 µl/plate)	16 ± 1	21 ± 7	7 ± 0	6 ± 1	12 ± 1	13 ± 3	103 ± 2	104 ± 8	12 ± 1	11 ± 1
(150 µl/plate)	18 ± 4	22 ± 4	6 ± 3	8 ± 2	11 ± 0	16 ± 2	110 ± 4	97 ± 4	14 ± 1	10 ± 1

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* Mean of 2 replicate plates ± standard error of the mean.
** Dissolved/diluted in dimethylsulfoxide (DMSO).
*** Dissolved in sterile distilled water.
† Dissolved in 95% ethanol.
†† Too numerous to count.

Note: 1.0 mg/plate with all bugs toxic (#2468).
#2987 at 150 µl/plate toxic for all strains.

TABLE IV-4

AMES ASSAY III

SAMPLE #2471 - MEDIUM OIL

SAMPLE #2472 - TAR

	Revertants Per Plate*									
	TA-98		TA-1537		TA-1538		TA-100		TA-1535	
	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9
Control (DMSO)	15 ± 2	19 ± 1	9 ± 1	13 ± 1	6 ± 1	10 ± 1	69 ± 1	87 ± 4	11 ± 1	13 ± 1
2-Anthramine** (10 µg/plate)	22 ± 2	373 ± 40	10 ± 1	74 ± 5	9 ± 0	454 ± 33	80 ± 4	538 ± 56	11 ± 1	55 ± 3
Daunomycin*** (10 µg/plate)	363 ± 7	384 ± 10								
9-Aminoacridine† (50 µg/plate)			44 ± 6	59 ± 6						
2-Nitrofluorene** (10 µg/plate)					682 ± 27	424 ± 14				
Methylmethane sulfonate** (50 µg/plate)							157 ± 3	176 ± 8		
N-Methyl-N'-nitro-N-nitrosoguanidine** (50 µg/plate)									2511 ± 48	2219 ± 235
#2471 - Medium Oil**										
(0.01 µl/plate)	12 ± 3	16 ± 3	8 ± 2	7 ± 2	6 ± 0	7 ± 2	64 ± 1	73 ± 10	9 ± 1	8 ± 1
(0.015 µl/plate)	5 ± 0	11 ± 2	7 ± 1	10 ± 0	6 ± 2	11 ± 0	71 ± 7	62 ± 2	12 ± 2	5 ± 1
(0.02 µl/plate)	9 ± 4	13 ± 1	6 ± 1	8 ± 1	8 ± 1	13 ± 4	58 ± 5	72 ± 1	10 ± 0	7 ± 0
(0.025 µl/plate)	14 ± 0	21 ± 1	4 ± 2	13 ± 2	7 ± 2	12 ± 2	51 ± 3	64 ± 5	8 ± 2	8 ± 1
#2472 - Tar**										
(0.01 µl/plate)	12 ± 0	28 ± 4	6 ± 1	9 ± 1	10 ± 2	36 ± 2	62 ± 1	80 ± 11	8 ± 2	5 ± 1
(0.015 µl/plate)	6 ± 2	38 ± 1	6 ± 1	14 ± 2	10 ± 3	62 ± 2	47 ± 5	93 ± 3	8 ± 1	6 ± 0
(0.02 µl/plate)	19 ± 1	69 ± 0	4 ± 1	11 ± 3	12 ± 1	46 ± 4	71 ± 16	96 ± 5	11 ± 1	5 ± 1
(0.025 µl/plate)	18 ± 0	124 ± 3	4 ± 1	6 ± 1	4 ± 1	51 ± 0	56 ± 1	92 ± 2	10 ± 4	7 ± 1

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* Mean of 2 replicate plates ± standard error of the mean.

** Dissolved/diluted in dimethylsulfoxide (DMSO).

*** Dissolved in sterile distilled water.

† Dissolved in 95% ethanol.

TABLE IV-5

AMES ASSAY IV

SAMPLE #2473 - HEAVY TAR AND DUST

SAMPLE #1152A - LIGHT OIL

	Revertants Per Plate*									
	TA-98		TA-1537		TA-1538		TA-100		TA-1535	
	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9	-S9	+S9
Control (DMSO)	17 ± 3	21 ± 1	9 ± 0	10 ± 2	10 ± 1	14 ± 2	96 ± 4	106 ± 2	12 ± 2	15 ± 1
2-Anthramine** (10 μg/plate)	16 ± 1	256 ± 17	8 ± 1	31 ± 1	16 ± 5	288 ± 31	89 ± 6	541 ± 25	10 ± 1	40 ± 7
Daunomycin*** (10 μg/plate)	>500	>500								
9-Aminoacridine† (50 μg/plate)			46 ± 4	60 ± 1						
2-Nitrofluorene** (10 μg/plate)					239 ± 7	222 ± 4				
Methylmethane sulfonate** (50 μg/plate)							225 ± 8	188 ± 6		
N-Methyl-N'-nitro-N-nitrosoguanidine** (50 μg/plate)									2445 ± 134	2051 ± 58
#2473 - Heavy Tar and Dust**										
(0.01 μl/plate)	11 ± 0	31 ± 3	5 ± 1	9 ± 1	6 ± 1	30 ± 1	96 ± 0	89 ± 8	9 ± 0	8 ± 1
(0.015 μl/plate)	24 ± 1	31 ± 2	5 ± 1	11 ± 1	8 ± 0	55 ± 6	98 ± 15	95 ± 1	10 ± 1	11 ± 0
(0.02 μl/plate)	8 ± 1	60 ± 6	5 ± 1	8 ± 2	9 ± 1	62 ± 2	85 ± 2	79 ± 3	5 ± 2	8 ± 2
(0.025 μl/plate)	9 ± 0	82 ± 3	5 ± 1	12 ± 1	6 ± 1	66 ± 2	94 ± 1	87 ± 2	3 ± 1	3 ± 0
#1152A - Light Oil**										
(0.01 μl/plate)	11 ± 1	14 ± 1	4 ± 1	6 ± 1	8 ± 2	10 ± 1	73 ± 2	64 ± 1	8 ± 1	6 ± 0
(0.015 μl/plate)	9 ± 1	18 ± 1	4 ± 0	5 ± 1	7 ± 1	14 ± 2	62 ± 2	66 ± 1	7 ± 2	7 ± 2
(0.02 μl/plate)	8 ± 1	16 ± 1	6 ± 1	7 ± 1	12 ± 1	15 ± 3	67 ± 5	47 ± 1	10 ± 2	6 ± 0
(0.025 μl/plate)	10 ± 1	11 ± 1	4 ± 1	6 ± 1	6 ± 1	10 ± 0	88 ± 7	81 ± 11	10 ± 2	5 ± 1

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* Mean of 2 replicate plates ± standard error of the mean.
** Dissolved/diluted in dimethylsulfoxide (DMSO).
*** Dissolved in sterile distilled water.
† Dissolved in 95% ethanol.

V. IN VITRO CYTOTOXICITY ASSAYS

Summary results for all cytotoxicity assays are given in Table V-1.

A. RABBIT ALVEOLAR MACROPHAGE (RAM) ASSAY

Test Sample: 2468

SUMMARY

Sample 2468 was assayed in triplicate in the RAM assay at 1000, 300, 100, 30 and 10 μg/ml. Determinations of total cell counts, cell viability (trypan blue exclusion), protein and ATP levels made at 20 hours showed EC_{50} values for these parameters to be >1000 μg/ml.

MATERIALS

Sample 2468 was described as a Slag sample. See Section I. The sample as received was tested for bacterial contamination before assay by inoculation into Trypticase Soy Broth, Thioglycollate Broth and Saubouraud Liquid Broth. Sample 2468 was found to be contaminated, but only after nine days of incubation both at 37°C and at room temperature. Since the RAM assay is conducted in Medium 199 supplemented with 100 units of penicillin and 100 μg of streptomycin per ml and the sample is only in the test system for 20 hours, this sample was considered suitable for bioassay.

METHODS

One New Zealand albino (SPF) ♂ rabbit, purchased from Charles River Breeding Laboratories, Wilmington, MA, was received on May 2, 1980, and housed alone in Room 13A of 38 Memorial Drive, Cambridge, MA, until May 5, 1980. The animal was sacrificed following the protocol of Coffin *et al.* (Arch. Environ. Health, 1968, 16:633-636) with 150 mg Nembutal injected into the marginal ear vein. A tracheostomy was performed, and the macrophages were collected using 5 instillation volumes of 30 ml of prewarmed (37°C) sterile 0.9% physiological saline.

The method for the RAM assay is described in the IERL-RTP Procedures Manual, Level 1, EPA 600/6-77-04, April, 1977. Macrophages were centrifuged in 50 ml sterile tubes for seven minutes at 800 rpm and 9°C, and resuspended in fresh physiological saline. Slides were made and the viability of cells was determined. The cells were re-centrifuged and suspended in an appropriate volume of Medium 199. Two ml of cells (1.8×10^6 cells) were added to each 25 cm^2 flask. Two ml of the appropriate dilution of sample 2468 or of the vehicle control were then added. The flasks were placed on a rocker platform in a 37°C humidified 5% CO_2 atmosphere and incubated for 20 hours. At the end of the 20-hour incubation period, cell viability, total protein and ATP content were determined.

RESULTS

Sample 2468 gave an EC_{50} value of >1000 µg/ml for total cell counts, cell viability (trypan blue exclusion), protein and ATP levels at 20 hours. Detailed results are shown in Table V-2 and Figure V-1.

B. CHINESE HAMSTER OVARY (CHO) CLONAL TOXICITY ASSAY

Test Samples:

2987	1152A
2988	2471
2468L	2472
2473L	2473

SUMMARY

The above samples were assayed in triplicate in the CHO assay at concentrations of 600, 200, 60, 20 and 6 µg/ml for solid samples (2987, 2988, 2468L and 2473L) and at 2.0, 0.2, 0.06, 0.02, 0.006, 0.002 and 0.0002 µl/ml for liquid samples (1152A, 2471, 2472 and 2473). Sample 2468L had no detectable toxicity. Sample 2473L had low toxicity. Samples 2987 and 2988 had moderate toxicity. Samples 1152A, 2471, 2472 and 2473 had high toxicity. A summary of these results is shown in Table V-1.

MATERIALS

Sample identifications are given in Section I. Note that samples 1152A, 2471, 2472 and 2473 were extracted with CH_2Cl_2 and solvent-exchanged with DMSO as described in Section III before use in this bioassay.

The samples, following extraction and solvent exchange, were tested for bacterial contamination before assay by inoculation into Nutrient Broth and Nutrient Agar at 25°C and 37°C and were found to be suitable for application to the in vitro assay.

METHODS

Chinese hamster ovary fibroblasts were removed from the liquid nitrogen frozen tumor bank on April 15, 1980, and maintained as monolayer cultures in Dulbecco's modified Eagle's Minimum Essential Medium supplemented with 10% fetal calf serum, 100 U/ml penicillin and 100 μg/ml streptomycin until May 12, 1980. At that time, the medium was changed to complete Ham's F-12 which was used for all subsequent cell passages and testing.

Liquid samples 2987, 2988, 2468L and 2473L were assayed in a single experiment on May 20, 1980 (Experiment 1). CHO cells in logarithmic growth phase from passage 7 were suspended at 50 cells/ml and 4 ml of this cell suspension were dispensed into each of 60 mm tissue culture dishes. Cells were allowed to adhere for six hours in a humidified 5% CO_2 atmosphere at 37°C. The medium was aspirated and 4 ml of the samples appropriately diluted in 2.5X complete medium were added. Cultures treated with sodium azide (NaN_3, 600 and 100 μg/ml) and untreated cultures were also used. The dishes were returned to the incubator for an additional 24 hours after which time all dishes were washed three times with phosphate buffered saline and refed with 5 ml of complete Ham's F-12 medium. All dishes were returned to the incubator for an additional six days to allow clones to develop. At the end of the final incubation period, all dishes were drained, washed once with phosphate buffered saline, fixed for at least 15 minutes with 100% methanol and stained 10-15 minutes with 10% Giemsa. Colony counts were determined on an Artec Colony Counter.

Extracted, solvent-exchanged samples 1152A, 2471, 2472 and 2473 were assayed in a single experiment on June 12, 1980 (Experiment 2). Because of the volatility of these samples, even after solvent exchange, the highest concentrations were assayed in tightly stoppered tissue culture flasks rather than in tissue culture dishes. The limiting factor in the testing of these samples was the concentration of the organic solvent dimethylsulfoxide (DMSO) which has been set at 2% to avoid solvent toxicity. Therefore, the highest concentration of sample tested was 20 μl/ml of the extracted material, or 2 μl/ml of the original sample.

CHO cells from passage 14 were suspended at 50 cells/ml in Ham's F-12 and flasks and dishes were inoculated with 4 ml of a cell suspension containing 50 cells/ml. The cells were allowed to adhere for six hours in a humidified 5% CO_2 atmosphere at 37°C. The medium was then aspirated and 4 ml of the appropriately diluted sample in complete Ham's F-12 was added. Untreated flask and dish cultures were included as media controls. Cultures in dishes were treated with sodium azide at 600 and 100 μg/ml (positive controls) and with 20 and 2 μl of DMSO (vehicle controls). The 25 cm^2 flasks which received the highest test sample concentrations were tightly stoppered and all dishes and flasks were returned to the incubator for an additional 24 hours. The pH of all dilutions of sample 1152A and of all controls was 7. Culture medium containing the highest two concentrations of samples 2471, 2472 and 2473 was very murky although the lower concentrations which were clear had a pH of 7.

All cultures were drained after 24 hours and washed three times with phosphate buffered saline. Cultures were refed with complete Ham's F-12. The cultures treated with 20 μl/ml of samples 2471, 2472 and 2743 (flasks) showed evidence of sample remaining after the three washes. The pH of all flasks (controls and samples) was slightly basic; all plates had a pH of approximately 7.

The media from all cultures were drained after six additional days of incubation. The colonies were fixed with 100% methanol and stained with 10% Giemsa. The plates were counted on the Artec Colony Counter and the flasks were counted manually.

RESULTS

Detailed results for samples 2987, 2988, 2468L and 2473L are shown in Table V-3 and Figure V-2. The response of CHO cells to NaN_3 (EC_{50} = 280 μg/ml) is comparable to that reported by others (Dr. B. Myer, Litton Bionetics, personal communication). The surviving fraction of CHO cells treated with 600 μl/ml of sample 2468L was 0.58; thus, the EC_{50} for this sample is reported as >600 μg/ml. EC_{50}'s for other samples are: 2987, 37 μl/ml; 2988, 98μl/ml and 2473L, 120 μl/ml. According to present EPA practice, these samples would be classified as having: no detectable toxicity, sample 2468L; low toxicity, sample 2473L; and moderate toxicity, samples 2987 and 2988.

Detailed results for samples 1152A, 2471, 2472 and 2473 are shown in Table V-4 and in the left panel of Figure V-3. The response of CHO cells to NaN_3 is shown in the right panel of this figure; the EC_{50} for NaN_3 is 260 μg/ml. Cells treated with 20 μl and 2 μl DMSO (solvent control, left panel) had a mean surviving fraction of 0.98, comparable to media control dishes. The number of clones formed by untreated control cells cultured in flasks was slightly lower (mean, 178) than that of cells cultured in dishes (188). Surviving fractions of cells treated with 20 μl of all samples and with 2 μl of sample 2472 (which had been tested in flasks due to their volatility) were calculated with respect to the appropriate number of clones obtained in flask-cultured control cells. The EC_{50}'s in μl/ml for the test samples are: 1152, 0.68; 2471, 0.11; 2472, 0.034; and 2473, 0.072. According to present EPA practice, all of these samples would be classified as having high toxicity.

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TABLE V-1

SUMMARY OF RESULTS OF IN VITRO TOXICITY TESTS

Sample	Description	Test System	Toxicity (EC_{50})
2468	Slag	RAM	No detectable toxicity (>1000 μg/ml)
2987	Wastewater	CHO	Moderate toxicity (37 μl/ml)
2988	Treated wastewater	CHO	Moderate toxicity (98 μl/ml)
2468L	ASTM Slag leachate	CHO	No detectable toxicity (>600 μl/ml)
2473L	ASTM Heavy tar leachate	CHO	Low toxicity (120 μl/ml)
1152A	Light oil	CHO	High toxicity (0.68 μl/ml)
2471	Medium oil	CHO	High toxicity (0.11 μl/ml)
2472	Tar	CHO	High toxicity (0.034 μl/ml)
2473	Heavy tar and dust	CHO	High toxicity (0.072 μl/ml)

TABLE V-2

RESULTS OF RAM ASSAY OF RADIAN SAMPLE 2468

Concentration	% Viable	Viability Index	Total Protein		ATP	
			µg/ml	% T/C	fg/10^6 Cells	% T/C
1000 µg/ml	66.9	59.4	-	-	-	-
	69.0	58.2	101.1	87.0	1.28 x 10^9	101.3
	66.2	56.2	113.1	97.3	0.98 x 10^9	77.5
$\bar{x}$	67.4	57.9	107.1	92.2	1.13 x 10^9	89.4
300 µg/ml	78.7	69.9	101.1	87.0	1.45 x 10^9	114.7
	83.1	75.2	121.8	104.8	1.79 x 10^9	141.6
	86.9	88.8	109.9	94.6	1.22 x 10^9	96.5
$\bar{x}$	82.9	78.0	110.9	95.5	1.49 x 10^9	117.6
100 µg/ml	85.7	84.7	86.2	74.2	1.17 x 10^9	92.6
	85.9	82.1	98.3	84.6	1.30 x 10^9	102.8
	70.0	59.1	91.8	79.0	0.83 x 10^9	65.7
$\bar{x}$	80.5	75.3	92.1	79.3	1.10 x 10^9	86.9
30 µg/ml	90.2	95.7	97.6	84.0	1.23 x 10^9	97.3
	93.3	92.8	-	-	1.44 x 10^9	113.9
	90.8	84.7	95.5	82.2	0.67 x 10^9	53.0
$\bar{x}$	91.4	91.1	96.5	83.1	1.11 x 10^9	88.0
10 µg/ml	93.0	88.8	113.8	98.0	1.18 x 10^9	93.4
	94.5	96.1	133.1	114.6	0.90 x 10^9	71.2
	92.9	87.7	128.4	110.5	0.96 x 10^9	75.9
$\bar{x}$	93.5	90.9	125.1	107.7	1.01 x 10^9	80.2
Controls	94.9		125.4		1.70 x 10^9	
	95.1		114.1		1.40 x 10^9	
	94.2		123.3		1.04 x 10^9	
	88.6		124.0		1.25 x 10^9	
	91.3		130.8		1.39 x 10^9	
	95.4		110.1		1.19 x 10^9	
	89.4		99.0		0.94 x 10^9	
	93.3		102.6		1.20 x 10^9	
$\bar{x}$	92.8		116.2		1.26 x 10^9	

TABLE V-2

RESULTS OF RAM ASSAY OF RADIAN SAMPLE 2468

(continued)

Footnote

Quality Control Data and Results of RAM Assay of Sample 2468:

No. of Rabbits Used	1 (SPF)
Viability of Macrophages	96.9%
Total Cell Number Recovered	4.3×10^7
Dilution Volume	48 ml Medium 199
Cells/ml	9.0×10^5
% Macrophages	98.5
Incubation Time	20 hours
pH of Samples (T_o)	∿7
pH of Samples (T_{20})	∿7 except #3 @ 100 μg/ml
Vehcile Used	Medium 199
ED_{50} Values	
Cell Count	>1000 μg/ml
Viability	>1000 μg/ml
Viability Index	>1000 μg/ml
Protein	>1000 μg/ml
ATP	>1000 μg/ml

FIGURE V-1

RADIAN RAM ASSAY

SAMPLE 2468

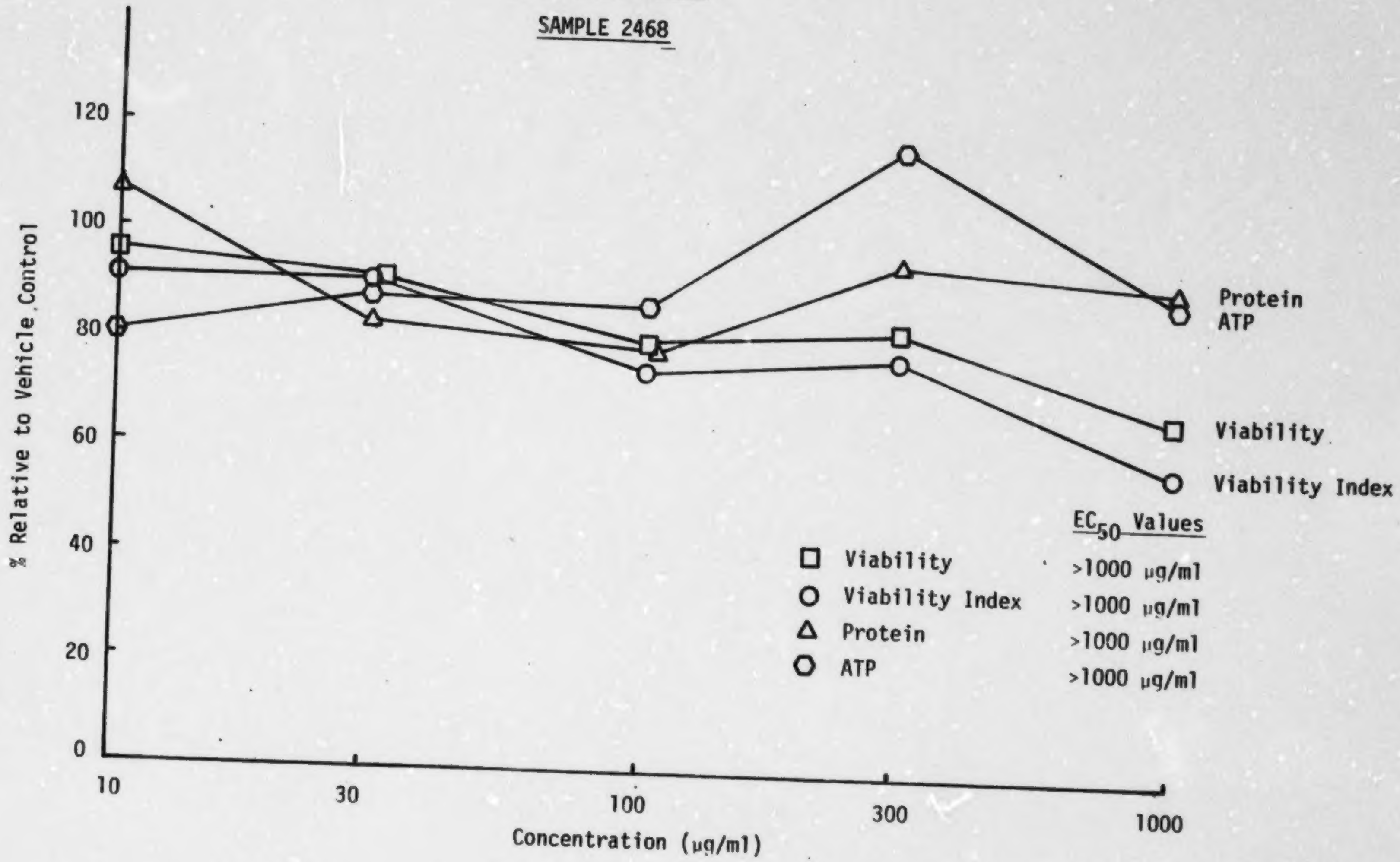


TABLE V-3

CHO CLONAL TOXICITY ASSAY RESULTS - EXPERIMENT NO. 1

Sample	Concentration	pH	No. of Colonies	Surviving Fraction
Untreated Control	-	7.0	190	1.00
			154	1.00
			155	1.00
			176	1.00
			149	1.00
			172	1.00
			149	1.00
			155	1.00
			192	1.00
			170	1.00
			174	1.00
			171	1.00
			166	1.00
			168	1.00
			150	1.00
Mean ± Standard Deviation			166.1 ± 13.9*	1.00
Positive Control (NaN_3)	600 µg/ml	7.0	48	0.29
			64	0.39
			54	0.31
			69	0.42
			64	0.39
Mean ± Standard Deviation			59.8 ± 8.6*	0.36 ± 0.06**
NaN_3	100 µg/ml	7.0	106	0.64
			110	0.66
			121	0.74
			115	0.70
			119	0.72
Mean ± Standard Deviation			114.2 ± 6.2*	0.69 ± 0.07**

TABLE V-3

CHO CLONAL TOXICITY ASSAY RESULTS - EXPERIMENT NO. 1

(continued)

	pH	Colony Counts (μg/ml) 600	200	60	20	6
2987	7.0	0	0	38	147	178
		0	0	25	144	164
		0	0	22	168	176
Mean		0	0	28.3	153.0	172.7
Standard Deviation*		0	0	8.5	13.1	7.6
Surviving Fraction		0	0	0.17	0.92	1.04
Standard Deviation**				0.05	0.11	0.10
2988	7.0	0	0	135	173	166
		0	0	142	198	172
		0	0	136	175	185
Mean		0	0	137.7	182.0	174.3
Standard Deviation*		0	0	3.8	13.9	9.7
Surviving Fraction		0	0	0.83	1.10	1.05
Standard Deviation**				0.08	0.12	0.11
2468L	7.0	109	144	187	174	173
		128	165	180	164	195
		112	161	150	151	164
Mean		116.3	156.7	172.3	163.0	177.3
Standard Deviation*		10.2	11.2	19.7	11.5	16.0
Surviving Fraction		0.77	0.94	1.04	0.98	1.07
Standard Deviation**		0.09	0.10	0.15	0.11	0.13
2473L	7.0	0	8	187	188	136
		0	4	171	198	168
		0	6	169	161	167
Mean		0	6.0	175.7	182.3	157.0
Standard Deviation*		0	2.0	9.9	19.1	18.2
Surviving Fraction		0	0.04	1.06	1.10	0.95
Standard Deviation**			0.01	0.11	0.15	0.14

---

* Standard Deviation $= \sqrt{\left(\frac{\Sigma X^2}{N} - \frac{\Sigma X^2}{N^2}\right) \times \frac{N}{N-1}}$

** Standard Deviation $\simeq \sqrt{\frac{\text{Var } T + \left(\frac{T}{C}\right)^2 \text{VarC}}{C^2}}$

FIGURE V-2

RADIAN CHO CLONAL TOXICITY ASSAY

EXPERIMENT NO. 1

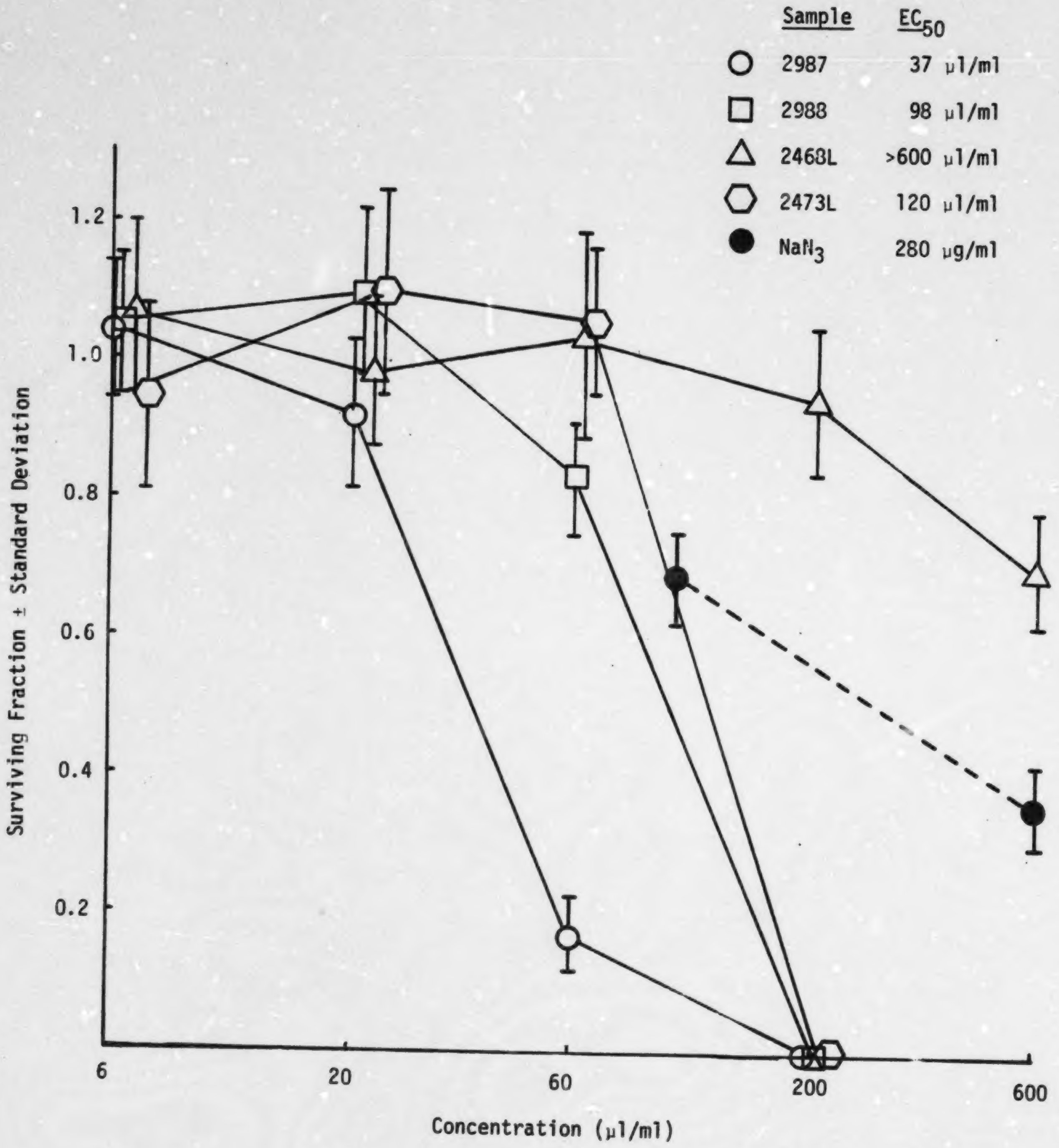


TABLE V-4

CHO CLONAL TOXICITY ASSAY RESULTS - EXPERIMENT NO. 2

Sample	Concentration	pH	No. of Colonies	Surviving Fraction
Media Control (60 mm dishes)	-	7.0	190	1.00
			175	1.00
			206	1.00
			179	1.00
			185	1.00
			199	1.00
			194	1.00
			196	1.00
			188	1.00
			188	1.00
			201	1.00
			189	1.00
			170	1.00
			180	1.00
			195	1.00
			188	1.00
Mean ± Standard Deviation			188.3 ± 10.2*	1.00
Media Control (25 cm^2 flasks)	-	7.2	195	1.00
			165	1.00
			189	1.00
			162	1.00
			166	1.00
			203	1.00
			188	1.00
			167	1.00
Mean ± Standard Deviation			178.6 ± 15.8*	1.00
Vehicle Control (DMSO)	20 µl/ml	7.0	201	1.07
			199	1.06
			179	0.96
			199	1.06
			159	0.85
			193	1.03
			185	0.99
			168	0.89
Mean ± Standard Deviation			188.4 ± 15.6*	0.98 ± 0.10**

TABLE V-4

CHO CLONAL TOXICITY ASSAY RESULTS - EXPERIMENT NO. 2

(continued)

Sample	Concentration	pH	No. of Colonies	Surviving Fraction
Vehicle Control (DMSO)	2 µl/ml	7.0	194	1.03
			188	1.00
			178	0.95
			193	1.02
			180	0.96
			187	0.99
			189	1.00
			198	1.05
Mean ± Standard Deviation			188.4 ± 6.8*	1.00 ± 0.06**
Positive Control (NaN_3)	600 µg/ml	7.0	14	0.07
			24	0.13
			28	0.15
			25	0.14
			28	0.15
Mean ± Standard Deviation			23.8 ± 5.8*	0.13 ± 0.03**
NaN_3	100 µg/ml	7.0	100	0.53
			176	0.93
			199	1.06
			148	0.79
			183	0.98
			160	0.85
Mean ± Standard Deviation			173.2 ± 19.9*	0.92 ± 0.12**

TABLE V-4

CHO CLONAL TOXICITY ASSAY RESULTS - EXPERIMENT NO. 2

(continued)

		Colony Counts (µl/ml)						
	pH	2.0	0.2	0.06	0.02	0.006	0.002	0.0002
1152A	7.0-7.2	13	190	171	177	175	166	166
		18	168	154	191	203	166	169
		17	189	190	173	172	166	160
Mean		16.0	182.3	171.7	180.3	183.3	166.0	165.0
Standard Deviation*		2.7	12.4	18.0	9.5	17.1	0	4.9
Surviving Fraction		0.09	0.97	0.91	0.96	0.97	0.88	0.88
Standard Deviation**		0.02	0.08	0.11	0.07	0.10	0.05	0.05
2471	7.0-7.2	0	2	165	180	188	189	177
		0	1	185	174	206	193	191
		0	8	189	192	182	200	177
Mean		0	3.7	179.7	182.0	192.0	194.0	181.7
Standard Deviation*			3.8	12.9	9.2	12.5	5.6	8.1
Surviving Fraction		0	0.02	0.95	0.97	1.02	1.03	0.97
Standard Deviation**			0.02	0.09	0.07	0.09	0.06	0.07
2472	7.0-7.2	0	0	13	183	170	184	195$^{\Delta}$
		0	0	29	169	184	185	297$^{\Delta}$
		0	0	13	167	182	202	428$^{\Delta}$
Mean		0	0	18.3	173.0	178.7	193.3	
Standard Deviation*				9.2	8.7	7.6	10.1	
Surviving Fraction		0	0	0.10	0.92	0.95	1.01	
Standard Deviation**				0.05	0.07	0.07	0.08	
2473	7.0-7.2	0	1	94	147	172	180	174
		0	0	123	155	150	185	169
		0	0	122	137	150	168	173
Mean		0	0.33	113.0	146.3	157.3	177.7	172.0
Standard Deviation*			0.58	16.5	9.0	12.7	8.7	2.7
Surviving Fraction		0	0.002	0.60	0.78	0.84	0.94	0.91
Standard Deviation**			0.003	0.09	0.06	0.08	0.07	0.05

* Standard Deviation $= \sqrt{\left(\frac{\Sigma X^2}{N} - \frac{\Sigma X^2}{N^2}\right) \times \frac{N}{N-T}}$

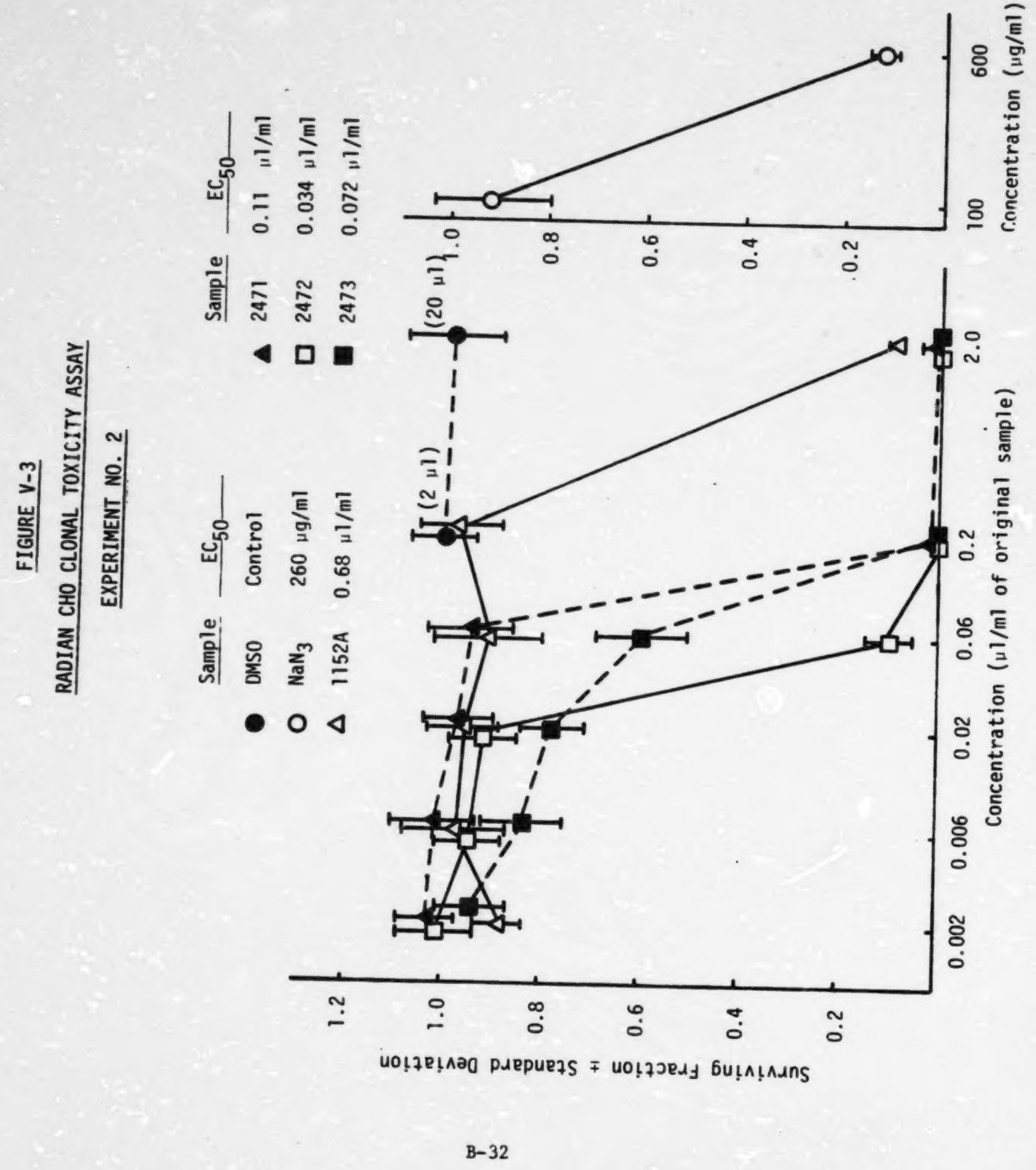
** Standard Deviation $\simeq \sqrt{\frac{\text{Var } T + \left(\frac{T}{C}\right)^2 \text{ Var} C}{C^2}}$

Δ Many very small colonies possibly due to excessive movement of dishes while washing at 24 hours or to initial inoculation error.

FIGURE V-3

RADIAN CHO CLONAL TOXICITY ASSAY

EXPERIMENT NO. 2



VI. ACUTE IN VIVO TOXICOLOGICAL TESTS IN RODENTS

Test Samples:

2468	2473
1152A	2987
2471	2988
2472	2468L
	2473L

SUMMARY

Each sample was administered by gavage as a single dose of 10 gm/kg or 10 ml/kg to male and female CDF_1 mice (5♂, 5♀). Animals were observed daily for signs of poor health. Surviving animals were killed and autopsied on the 15th day following dosing. Gross autopsy did not reveal any organ changes which appeared to be related to the test material. More than one-half of the test animals died following treatment with samples 1152A (7/10), 2471 (10/10) or 2472 (7/10). Three test animals died following administration of sample 2473. Zero or 1 death occurred after administration of 2468 (1/10), 2987 (1/10), 2988 (0/10), 2468L (1/10), 2473L (1/10). Two animals in the water control group, 2 animals in the Ky control group and 1 Trioctanoin control group died.

EPA Level 1 quantitative testing is recommended for 1152A, 2471, 2472 and 2473.

MATERIALS

The materials were received by Ms. Carolyn Creswell of Arthur D. Little, Inc., and were identified as follows:

Number	Description
2468	Slag
1152A*	Light Oil
2471*	Medium Oil
2472*	Tar
2473*	Heavy Tar and Dust
2987	Wastewater, COD = 17,700 mg/l
2988	Treated Wastewater, COD = 5,540 mg/l
2468L	ASTM Slag Leachate
2473L	ASTM Heavy Tar Leachate

---

* Handle with caution.

METHODS

A group of male and female CDF_1 mice was obtained from Charles River Breeding Laboratories and placed in quarantine for one week at Arthur D. Little, Inc., laboratories, 38 Memorial Drive, Cambridge, Massachusetts. From this group, five males and five females of comparable body weights were selected for testing of each compound. All selected animals appeared to be healthy.

Test material was administered by gavage in a single dose to each animal. The dose employed in each case was 10 gm/kg or 10 ml/kg.

Seven of the samples were used as received. Sample 2468 (Slag) was mixed with Ky lubricant* for dosing. Sample 2473 was slightly solubilized with trioctanoin** (6% by volume). Control animals were treated with 10 ml/kg of Ky lubricant or trioctanoin, respectively.

Body weights were recorded on day of dosing (Day 1), Day 8 and Day 15. Animals were observed daily for signs of poor health. A gross autopsy was performed on each animal at death or sacrifice. Organ weights were not obtained.

RESULTS

The results are summarized in Table VI-1 and individually presented in Tables VI-2 through VI-10. Mortality exceeding that of appropriate control groups was observed in groups treated with samples 1152A, 2471, 2472 and 2473. One animal which died was found to have a large axillary mass (Group 2473L). Deaths occurred in control groups as indicated in Tables VI-1-VI-10.

At autopsy, no organ changes were observed which appeared to be treatment related. Surviving animals in Group 1152A showed low body weights at Day 15. It is suspected that the delayed deaths in the control groups were related to difficulties in sample delivery.

---

* K-Y© Sterile Lubricant, Water Soluble, Johnson and Johnson, New Brunswick, New Jersey.

** Trioctanoin ($C_{27}H_{50}O_6$) Lot A8B, Eastman Kodak Co., Rochester, New York.

CONCLUSIONS

Testing of acute oral toxicity in rodents has demonstrated Samples 1152A, 2471, 2472 and 2473 to have greater lethal potential than the appropriate control vehicle.

Senior Technician Evaluating Material	Peter C. Rachwall Peter C. Rachwall
Subcase Leader and Unit Manager, Toxicology	Rosalind C Anderson Rosalind C. Anderson, Ph.D.
Case Leader	Mildred G. Broome Mildred G. Broome, Ph.D.
Vice-President, Section Manager Bio/Medical Sciences Section	Andrew Sivak, Ph.D.

TABLE VI-1

SUMMARY OF RESULTS OF ACUTE ORAL TOXICITY TESTS

Compound \#	Mortality (Day 15)	Day of Death	% Weight Gain (Day 15)
2468 in Ky	1/10	Day 4	9%
Ky Control	2/10	2-Day 4	9%
1152A	7/10	5-Day 1, 2-Day 2	0%
2471	10/10	10-Day 1	---
2472	7/10	3-Day 1, 3-Day 2, 1-Day 5	4%
2987	1/10	Day 7	4%
2988	0/10	----	9%
Water Control	2/10	1-Day 6, 1-Day 8	14%
2473 + Trioctanoin	3/10	1-Day 1, 2-Day 5	4%
Trioctanoin Control	1/10	1-Day 7	9%
2468L	1/10	1-Day 6	9%
2473L	*1/10	1-Day 13	4%
Leachate Control	0/10	-----	9%

---

* Large mass possible cause of death.

TABLE VI-2

SUMMARY OF SINGLE-DOSE ORAL TOXICITY OF 2468

Species:		Mouse
Strain:		CDF_1
Body Weight Range (gm):		
Day 1	19-27	
Day 8	21-27	
Day 15	22-29	
Formulation:		Mixed with Ky lubricant
Concentration (gm/ml):		0.54 gram/ml
Approximate Volume Administered:		0.42 ml

Dosage (gm/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Control Ky 10 gm/kg	2/10	2/10	4%	9%
2468 in Ky 10 gm/kg	1/10	1/10	4%	9%

Numbers rounded to nearest integer

TABLE VI-3

SUMMARY OF SINGLE-DOSE ORAL TOXICITY OF 1152A

Species:		Mouse
Strain:		CDF_1
Body Weight Range (gm):		
Day 1	19-24	
Day 8	19-26	
Day 15	21-27	
Formulation:		Used as Received
Concentration (gm/ml):		Unknown
Approximate Volume Administered:		0.21ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Control Water 10 ml/kg	2/10	2/10	9%	14%
1152A 10 ml/kg	7/10	7/10	-10%	0%

Numbers rounded to nearest integer

TABLE VI-4

SUMMARY OF SINGLE-DOSE ORAL TOXICITY OF 2471

Species:		Mouse
Strain:		CDF_1
Body Weight Range (gm):		
Day 1	19-26	
Day 8	19-26	
Day 15	21-27	
Formulation:		Used as Received
Concentration (gm/ml):		Unknown
Approximate Volume Administered:		0.22 ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Control Water 10 ml/kg	2/10	2/10	9%	14%
2471 10 ml/kg	10/10	10/10	--	--

Numbers rounded to nearest integer

TABLE VI-5

SUMMARY OF SINGLE-DOSE ORAL TOXICITY OF 2472

Species:		Mouse
Strain:		CDF_1
Body Weight Range (gm):		
Day 1	19-26	
Day 8	19-26	
Day 15	21-27	
Formulation:		Used as Received
Concentration (gm/ml):		Unknown
Approximate Volume Administered		0.22 ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Control Water 10 ml/kg	2/10	2/10	9%	14%
2472 10 ml/kg	7/10	7/10	0%	4%

Numbers rounded to nearest integer

TABLE VI-6

SUMMARY OF SINGLE-DOSE ORAL TOXICITY OF 2473

Species:		Mouse
Strain:		CDF_1
Body Weight Range (gm):		
Day 1	16-25	
Day 8	18-27	
Day 15	20-29	
Formulation:		Trioctanoin (6% by volume) added to facilitate delivery
Concentration (gm/ml):		Unknown
Approximate Volume Administered		0.22 ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Control Trioctanoin 10 ml/kg	0/10	1/10	0%	9%
2473 + 6% Trioctanoin 10 ml/kg	3/10	3/10	0%	4%

Numbers rounded to nearest integer

TABLE VI-7

SUMMARY OF SINGLE-DOSE ORAL TOXICITY OF 2987

Species:		Mouse
Strain:		CDF_1
Body Weight Range (gm):		
Day 1	19-25	
Day 8	19-26	
Day 15	19-27	
Formulation:		Used as Received
Concentration (gm/ml):		Unknown
Approximate Volume Administered		0.22 ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Control, Water 10 ml/kg	2/10	2/10	9%	14%
2987 10 ml/kg	1/10	1/10	4%	4%

Numbers rounded to nearest integer

TABLE VI-8

SUMMARY OF SINGLE-DOSE ORAL TOXICITY OF 2988

Species:		Mouse
Strain:		CDF_1
Body Weight Range (gm):		
Day 1	19-23	
Day 8	19-26	
Day 15	21-28	
Formulation:		Used as Received
Concentration (gm/ml):		Unknown
Approximate Volume Administered		0.22 ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Control, Water 10 ml/kg	2/10	2/10	9%	14%
2988 10 ml/kg	0/10	0/10	4%	9%

Numbers rounded to nearest integer

TABLE VI-9

SUMMARY OF SINGLE-DOSE ORAL TOXICITY OF 2468L

Species:		Mouse
Strain		CDF_1
Body Weight Range (gm):		
Day 1	19-24	
Day 8	19-27	
Day 15	21-28	
Formulation:		Used as Received
Concentration (gm/ml):		Unknown
Approximate Volume Administered		0.22 ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Leachate 10 ml/kg	0/10	0/10	4%	9%
2468L 10 ml/kg	1/10	1/10	4%	9%

Numbers rounded to nearest integer

TABLE VI-10

SUMMARY OF SINGLE-DOSE ORAL TOXICITY OF 2473L

Species:		Mouse
Strain:		CDF_1
Body Weight Range (gm):		
Day 1	19-26	
Day 8	19-27	
Day 15	20-28	
Formulation:		Used as Received
Concentration (gm/ml):		Unknown
Approximate Volume Administered		0.22 ml

Dosage (ml/kg), Mortality, and Percent Mean Body Weight Gain of Survivors Post-Treatment

Dosage	Mortality		% Mean Body Weight Gain	
	Day 8	Day 15	Day 8	Day 15
Leachate 10 ml/kg	0/10	0/10	4%	9%
2473L 10 ml/kg	0/10	1*/10	0%	4%

---

* Autopsy at 13 days showed large axillary mass.
Numbers rounded to nearest integer

APPENDIX C
MASS BALANCE CALCULATIONS

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APPENDIX C
MASS BALANCE CALCULATIONS

C1.0 INTRODUCTION

This appendix describes the calculations and assumptions used to derive carbon, sulfur, and nitrogen balances for the Kosovo gasification plant. Figures C.1-1 to C.1-3 summarize the overall results of these balances. The calculations used to obtain the results presented in these figures are given in Section C7.0.

Since the derivation of mass balances was not one of the objectives of the Kosovo test program, the data used to support these calculations are incomplete. However, the balances are presented to lend insight into the operation of the Kosovo plant. In performing these calculations, the values for stream composition and flow rate given as 'overall best values' in Appendix A were used. When experimental flow rate data were not available, design or estimated flow rates were used. All calculations are normalized to a one-gasifier-in-service basis.

In the carbon balance results presented in Figure C.1-1, the percentage of the carbon in the coal which is accounted for in the various product and waste streams is 93%. Most of the carbon entering with the coal was found in the clean product gas, the combined flare feed gas, and the CO_2-rich waste gas.

Figure C.1-2 shows the results from the sulfur mass balance calculations. The percentage of the sulfur in the coal accounted for in the product and waste streams is 175%. The poor accountability of this balance is probably due to variations in the input coal sulfur content as well as the use of the design rather than a measured flow rate value for the input coal. Regardless of the poor accountability, these results indicate that in this design most of the sulfur in the coal ends up in the flare feed stream.

Figure C.1-3 summarizes the nitrogen mass balance results. The percentage of the nitrogen entering with the coal and with the oxygen fed to the gasifiers accounted for in the product and waste streams is 51%. In analyzing gas phase results, it was sometimes difficult to discriminate between molecular nitrogen actually present in the sampled gas stream and nitrogen present due to sample contamination with air. Nitrogen data were not included in the nitrogen balances when the N_2/O_2 ratio in the analysis was similar to the 79/21 N_2/O_2 ratio found in air.

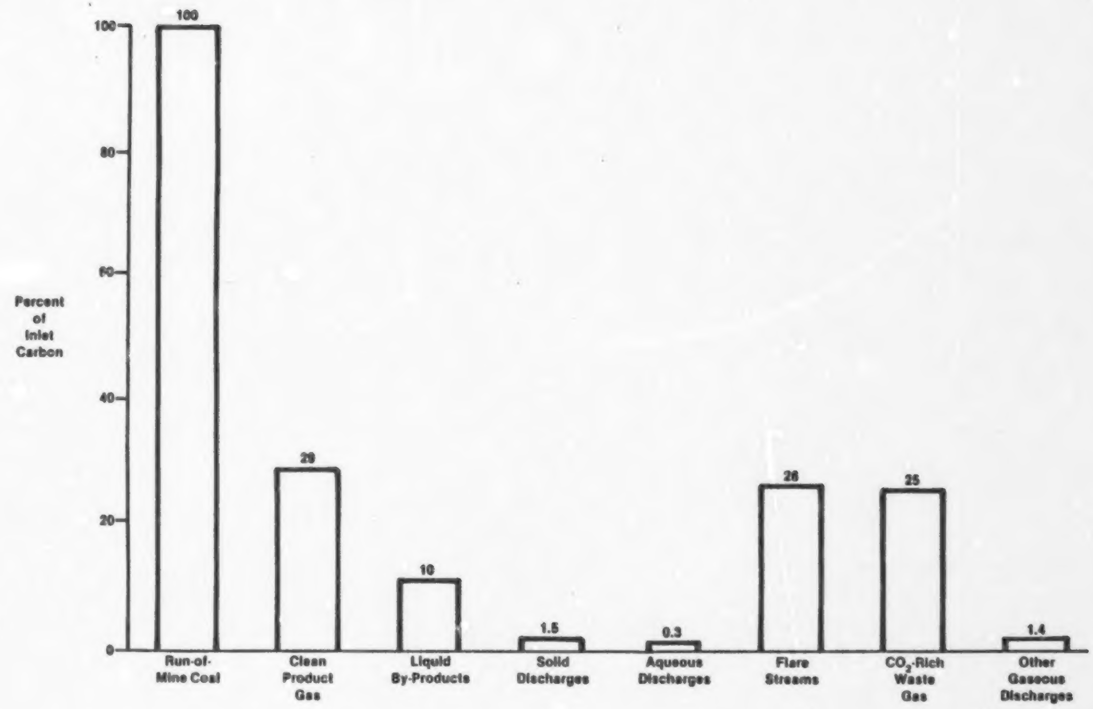

Figure C.1-1. A summary of Kosovo carbon mass balalnce results (93% accountability).

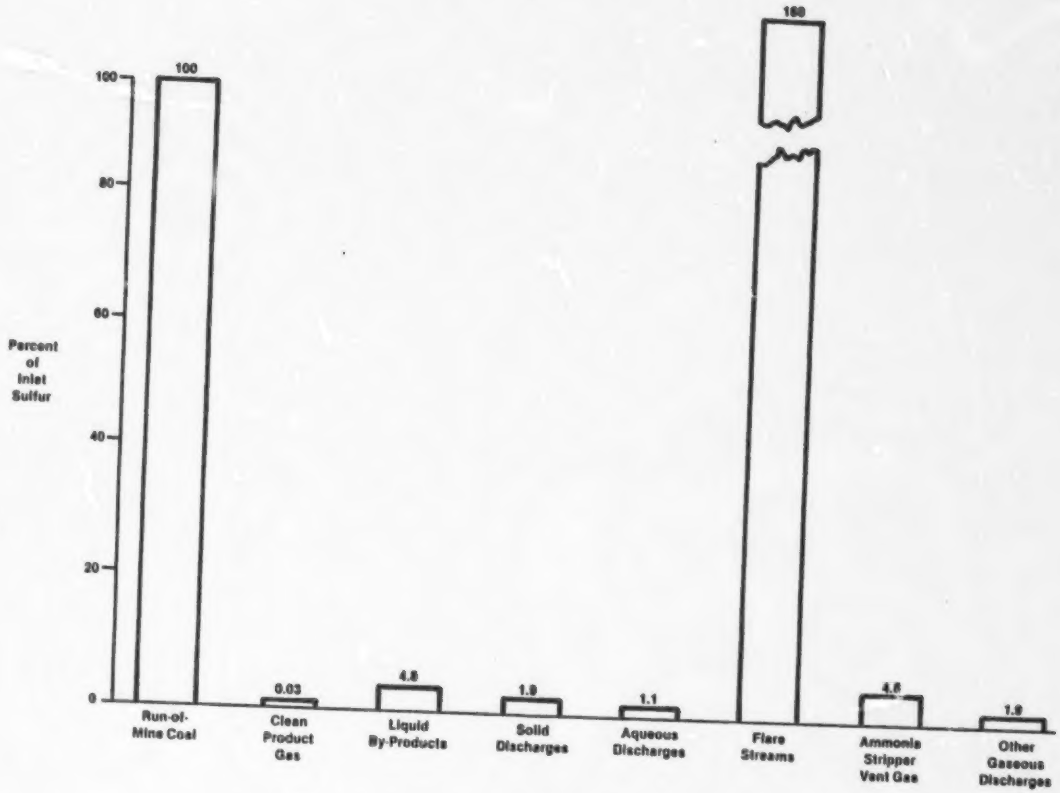

Figure C.1-2. A summary of Kosovo sulfur mass balance results (175% accountability).

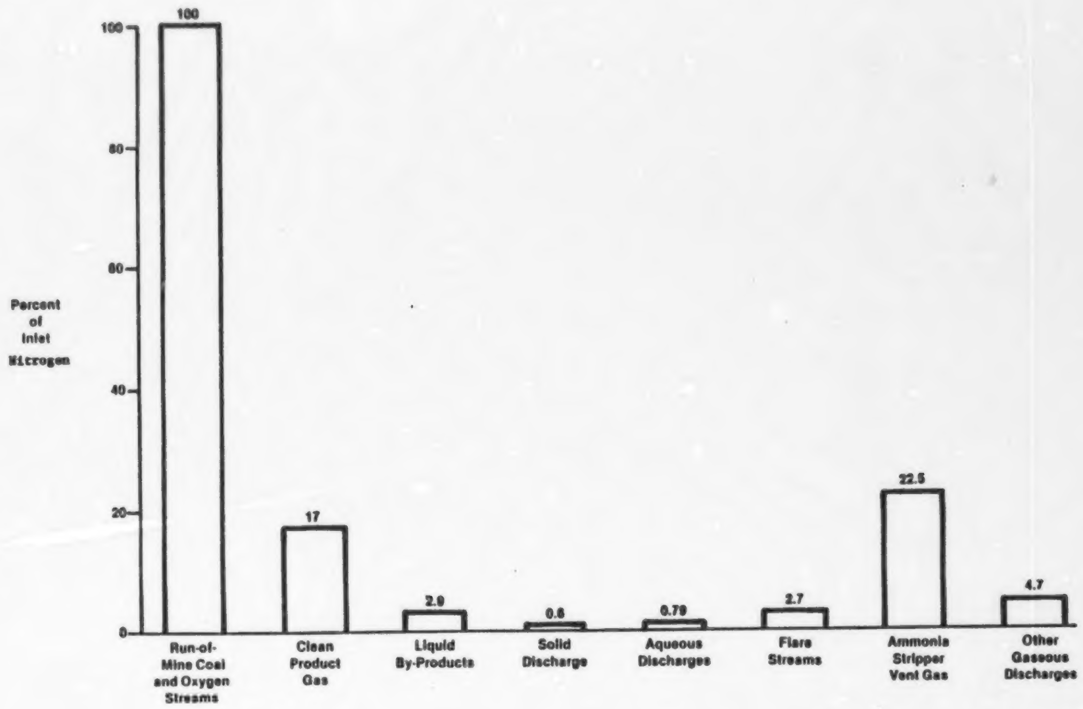

Figure C.1-3. A summary of Kosovo nitrogen mass balance results (51% accountability).

In addition to the overall mass balances summarized in Figures C.1-1 through C.1-3, carbon, sulfur, and nitrogen balances were performed for the following plant sections:

- Coal Drying (Section C2.0),
- Gas Production (Section C3.0),
- Rectisol (Section C4.0),
- Phenosolvan (Section C5.0), and
- the Flare System (Section C6.0).

Mass balances were also derived for 15 key inorganic trace elements. These balances are presented in Section C7.0.

C2.0 MASS BALANCE CALCULATIONS FOR THE KOSOVO COAL DRYING SECTION

Mass balances were calculated for carbon, sulfur, and nitrogen for the Kosovo Coal Drying section. The results are summarized in Table C.2-1.

Composition data were not available for the 'run-of-mine' coal input to the Coal Drying section. Therefore, these calculations could not be used to determine component accountabilities in this section.

The major inlet and outlet streams in the coal drying section are:

Inlet Streams:

- Wet 'Run-of-Mine' Coal
- High Pressure (3 MPa) Steam

Outlet Streams:

- Dried Coal
- Fleissner Condensate
- Autoclave Vent Gas
- Condensate Tank Vent Gas

During the Phase II test program, major component analyses were performed for the dried coal and Fleissner autoclave vent gas streams. The Fleissner condensate and the condensate tank vent gas were not analyzed.

TABLE C.2-1. KOSOVO COAL PREPARATION SECTION MASS BALANCE RESULTS

Stream	All values in kg/gasifier-hr Total Mass Flow	Carbon Mass Flow	Sulfur Mass Flow	Nitrogen Mass Flow
Inlet Streams:				
Run-of-Mine Coal (s)	2.4 E+04	ND	ND	ND
Outlet Streams:				
Dried Coal (s)	1.6 E+04	7.1 E+03	1.4 E+02	1.7 E+02
Autoclave Vent (g)	7.9 E+01	8.5 E+00	6.0 E-01	0*
TOTAL OUTLET		7.1 E+03	1.4 E+02	1.7 E+02

(s) - solid stream

(g) - gaseous stream

* - excluding molecular nitrogen

ND - no data available

Ultimate Analysis data for the dried coal are given in Table C.2-2. The data are reported in weight percent (wt %). To convert these data to mass flows, the following equation is used:

$$\text{Component Mass Flow Rate} = \left(\frac{\text{Component Concentration in wt \%}}{100}\right)\left(\text{Total Stream Flow Rate in kg/hr}\right) \quad (1)$$

For example, the dried coal carbon mass flow rate is calculated as follows:

$$\text{Dried Coal Carbon Mass Flow Rate} = \left(\frac{44.5}{100}\right)(1.6\text{E+0.4 kg/hr}) = 7.1\text{E+03 kg/gasifier-hr}$$

TABLE C.2-2. KOSOVO COAL PREPARATION SECTION SOLID STREAM DATA

Component	Dried Coal
Design Flow Rate (kg/gasifier-hr)	1.6 E+04
Ultimate Analysis (wt %)	
Moisture	20.2
Ash	14.3
Carbon	44.5
Sulfur	0.89
Hydrogen	3.51
Nitrogen	1.08
Oxygen	15.5
Chlorine	0.1

Table C.2-3 presents concentration and flow rate data for the autoclave vent gas. To determine the total carbon content of this gas, the moles of carbon in carbon-containing species must be summed. The carbon-containing species identified and quantified for the autoclave vent gas are shown in Table C.2-4. Also shown is the concentration of carbon contained in each species. The carbon concentration is found by multiplying the carbon-containing species concentration by the number of carbon atoms in the species. For example, for ethyl mercaptan (C_2H_5SH), the species concentration is 0.21 mole percent of C_2H_5SH in the gas. The carbon concentration is twice this value since there

TABLE C.2-3. KOSOVO COAL PREPARATION SECTION FLEISSNER AUTOCLAVE VENT FLOW RATE AND COMPOSITION DATA

Component	Value
Dry Gas Flow Rate (m^3/gasifier hr at 25°C)	57.8
Molecular Weight of Dry Gas	33.4
Composition Data (Dry Basis)	
Fixed Gases (vol %)	
H_2	Tr
O_2	14
N_2	56
CH_4	Tr
CO	Tr
CO_2	29
Sulfur Species (ppmv)	
H_2S	2400
COS	30
CH_3SH	3400
C_2H_5SH	2100
Hydrocarbons (vol %)	
C_2H_6	Tr
C_2H_4	NF
C_3's	0.03
C_4's	0.03
C_5's	NF
C_6^+	0.01
Aromatic Species (ppmv)	
Benzene	17
Toluene	6.8
Xylenes and Ethylbenzene	4.2
Phenols	-
Nitrogen Species (ppmv)	
NH_3	-
HCN	-

1 vol % = 1.0E+04 ppmv

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all other species

NF = Not Found

- = No Data Available

TABLE C.2-4. KOSOVO COAL PREPARATION SECTION FLEISSNER AUTOCLAVE VENT CARBON CONTENT DATA

Species	Species Concentration (mole %)*	Carbon Concentration** (%)
CH_4	1.0 E-02	1.0 E-02
CO	1.0 E-02	1.0 E-02
CO_2	2.9 E+01	2.9 E+01
CH_3SH	3.4 E-01	3.4 E-01
C_2H_5SH	2.1 E-01	4.2 E-01
C_2's (as C_2H_6)	1.0 E-04	2.0 E-04
C_3's (as C_3H_8)	3.0 E-02	9.0 E-02
C_4's (as C_4H_{10})	3.0 E-02	1.2 E-01
C_5's (as C_5H_{12})	-	-
C_6^+ (as C_6H_{14})	1.1 E-02	6.6 E-02
C_6H_6	1.7 E-03	1.0 E-02
C_7H_8	6.8 E-04	4.8 E-03
C_8H_{10}	4.2 E-04	3.4 E-03
Phenols (as C_6H_7O)	-	-
HCN	-	-
TOTAL		3.0 E+01

* moles of each species per 100 moles of gas

** g-atoms of carbon per 100 moles of gas are two carbon atoms in each ethyl mercaptan molecule. Summation of the individual carbon concentrations in Table C.2-4 yields the autoclave vent gas total carbon content of 30 g-atoms of carbon per 100 gmoles of gas.

It was assumed that the ideal gas law was valid for all gaseous streams. At the moderate (low pressure, usually low temperature) conditions encountered in the Kosovo plant, errors introduced by this assumption should be well within the experimental errors of gaseous stream flow rate and composition measurements. Using the ideal gas law, the volumetric flow rate (m³/hr) given in Table C.2-3 can be converted to a mass flow rate (kg/hr) using the following formula:

$$M = (V)\left(\frac{P}{RT}\right)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right)\left(\frac{1000}{\text{m}^3}\right)(MW_g) \qquad (2)$$

where: M = mass flow in kg/gasifier-hr

V = volumetric flow in m³/hr at Temperature T

P = pressure in atmospheres

R = gas constant = $\frac{0.0821\ \text{atm-}}{\text{gmol-K}}$

T = absolute temperature in K

MW_g = molecular weight of the gas

For the autoclave vent, the mass flow rate found using Equation 2 is:

$$\text{Autoclave Mass Flow} = (57.8)\left(\frac{1}{(298)(0.0821)}\right)(33.4) = 7.9\text{E+01 kg/gasifier-hr}$$

For an ideal gas, the volumetric concentration of a species is the same as the molar concentration (vol % = mole %). Using this relationship, the mass flow rate of a gaseous component can be calculated using the following equation:

$$M_i = \left(\frac{Y_i\ MW_i}{MW_g}\right) M_g \qquad (3)$$

where: M_i = mass flow of component i in kg/gasifier-hr

Y_i = volumetric or molar concentration of component i (g-atoms i/mole gas)

MW_i = molecular weight of component i

MW_g = molecular weight of the total gas stream

M_g = mass flow rate of the total gas in kg/gasifier-hr

For example, the carbon mass flow rate of the autoclave vent gas can be found from the total carbon concentration given in Table C.2-3 and the mass flow of the total gas stream (calculated above) using Equation 3:

$$\text{Autoclave Vent Carbon Mass Flow} = \frac{(0.30)(12)}{33.4}(7.9\text{E}+01) = 8.5\text{E}+00 \text{ kg/C gasifier-hr}$$

The total autoclave vent sulfur mass flow rate is also calculated using Equation 3. Sulfur species data are shown in Table C.2-5. The total sulfur concentration given in Table C.2-5 is 0.79 g-atoms of sulfur per 100 gmoles of gas. Therefore, using Equation 3, the sulfur mass flow in the autoclave vent is:

$$\text{Autoclave Vent Sulfur Mass Flow} = \frac{(0.0079)(32)}{33.4}(7.9\text{E}+01) = 6.0\text{E}-01 \text{ kg S/gasifier-hr}$$

The ratio of N_2 to O_2 given in Table C.2-3 for the autoclave vent is 80/21. This ratio is very close to the 79/21 N_2/O_2 ratio of air. Therefore, molecular nitrogen data for the autoclave vent were not used in the nitrogen species mass balance. Data were not available for NH_3 and HCN in the autoclave vent; therefore, this stream was not included in the nitrogen balance mass flow calculations.

TABLE C.2-5. KOSOVO COAL PREPARATION SECTION FLEISSNER AUTOCLAVE VENT SULFUR CONTENT DATA

Species	Species Concentration (mole %)*	Sulfur Concentration* (%)
H_2S	2.4 E-01	2.4 E-01
COS	3.0 E-03	3.0 E-03
CH_3SH	3.4 E-01	3.4 E-01
C_2H_5SH	2.1 E-01	2.1 E-01
TOTAL		7.9 E-01

*See notes for Table 2-4.

C3.0 MASS BALANCE CALCULATIONS FOR THE KOSOVO GAS PRODUCTION SECTION

Mass balances for carbon, sulfur, and nitrogen around the Kosovo Gas Production section are shown in Table C.3-1. There are three key inlet and eight key outlet streams in the Gas Production section. These streams are:

Inlet Streams:

- Dried Coal (from Coal Drying)
- Steam
- Oxygen

Outlet Streams:

- Crude Product Gas (to Rectisol)
- Gasifier Ash
- Gas Liquors (to Tar/Oil Separation)
- Coal Lock Bucket Vent Gas
- Low Pressure Coal Lock Vent Gas
- Gasifier Start-up Vent Gas
- Gas Liquor Tank Vent Gas
- Ash Cyclone Vent Gas
- High Pressure Coal Lock Vent Gas (to Flare System)

The gas liquor streams were not included in these calculations because they were not analyzed during the test program. The coal lock bucket vent was plugged during most of the test period. When this vent was plugged, the gas normally vented at this point was discharged through the L.P. coal lock event. Therefore, data for the coal lock bucket vent were not used. The gasifier start-up vent was in operation only during the start-up sequence and was likewise not included in these calculations.

The oxygen fed to the gasifiers normally contains about 96 vol % O_2 and 4 vol % N_2. The design flow rate of 2160 m³/gasifier-hr at 25°C was verified from process data to be representative of the oxygen input stream flow rate. This flow rate was converted from volumetric units (m³/hr) to mass units (kg/hr) using Equation 2:

$$\text{Oxygen Stream Mass Flow} = (2160\ \text{m}^3/\text{hr})\left(\frac{1}{(298)(0.0821)}\right)(31.8) = 2.8\text{E}{+}03\ \text{kg/gasifier-hr}$$

TABLE C.3-1. KOSOVO GAS PRODUCTIN SECTION MASS BALANCE RESULTS

	All values in kg/gasifier-hr			
Stream	Total Mass Flow	Carbon Mass Flow	Sulfur Mass Flow	Nitrogen Mass Flow
Inlet Streams:				
Dried Coal (s) (from Coal Preparation)	1.6 E+04	7.1 E+03	1.4 E+02	1.7 E+02
Oxygen	2.8 E+03	—	—	9.9 E+01
TOTAL INLET		7.1 E+03	1.4 E+02	2.8 E+02
Outlet Streams:				
Gasifier Ash (s)	2.7 E+03	4.7 E+01	2.4 E+00	8.1 E-01
Wastewater (aq)	2.6 E+03	—	5.0 E-01	8.3 E-03
Crude Product Gas (g) (to Rectisol)	1.7 E+04	5.7 E+03	1.7 E+02	1.4 E+02
Dedusting Cyclone Vent (g)	8.4 E+03	*	*	*
L.P. Coal Lock Vent (g)	2.0 E+01	6.4 E+00	3.7 E-01	7.9 E-02
Gas Liquor Tank Vent (g)	4.5 E+01	5.9 E-01	8.8 E-01	1.9 E-02
Ash Lock Cyclone Vent (g)	4.2 E+01	2.3 E+00	3.5 E-03	1.3 E+01
H.P. Coal Lock Vent (g) (to Flare System)	2.3 E+02	1.6 E+02	1.3 E+00	3.9 E-01
TOTAL OUTLET		5.9 E+03	1.7 E+02	1.5 E+02
Accountability (%)		83	123	55

* - Amounts are negligible in gaseous stream, particulate analysis not available.

— = No Data Available

(s) - solid stream

(g) - gaseous stream

(aq) - aqueous stream

TABLE C.3-2. KOSOVO GAS PRODUCTION SECTION GASIFIER ASH DATA

Component	Value
Flow Rate (kg/gasifier-hr)	2.7 E+03
Ultimate Analysis (wt%)	
Moisture	2.05
Ash	93.5
Carbon	1.74
Sulfur	0.15
Hydrogen	0.25
Nitrogen	0.03
Oxygen	2.3
Chlorine	0.04

The nitrogen mass flow rate was calculated using Equation 3:

$$\text{Nitrogen Mass Flow Rate in Input Oxygen} = (0.04)\left(\frac{28}{31.8}\right)(2.8\text{E+03 kg/hr}) = 9.9\text{E+01 kg N/hr}$$

The calculations necessary to define the inputs associated with the dried coal inlet stream were described in the Coal Drying section discussion. Table C.3-2 shows the Ultimate Analysis data used for the gasifier ash calculations. Also shown is the design flow rate of 2.7E+03 kg/gasifier-hr. Using the data in Table C.3-2, Equation 1 was used to calculate the component (carbon, sulfur, and nitrogen) flow rates in the gasifier ash discharge stream. The results are shown in Table C.3-1.

Table C.3-3 shows composition and flow rate data for Gas Production section gaseous outlet streams. The total carbon content of each vent is given in Table C.3-4. As with the Coal Drying section gaseous streams, the concentration of carbon-containing species is converted to carbon concentration by multiplying the carbon-containing species concentration by the number of carbon atoms in the species molecule. Individual carbon concentrations are then summed to yield the total stream carbon content. Gaseous stream flow rate data

TABLE C.3-3. FLOW RATE AND COMPOSITION DATA FOR KOSOVO GAS PRODUCTION SECTION GASEOUS STREAMS

	Dedusting Cyclone Vent	Low Pressure Coal Lock Vent	Gas Liquor Tank Vent	Ash Lock Cyclone Vent	High Pressure Coal Lock (Flare Feed)	Crude Product Gas
Dry Gas Flow Rate (m^3/gasifier-hr at 25°C)	7200	21	44	32.8	230	18,800
Molecular Wt. of Dry Gas	28.6	23.5	–	31.3	24.9	21.9
Composition (Dry Basis)						
Fixed Gases (vol %)						
H_2	NF	37	11.8	NF	32	38.1
O_2	20.8	0.27	13.8	48	0.24	0.36
N_2	78.2	0.18	55.6	35	0.14	0.64
CH_4	NF	8.6	–	Tr	10.5	11.5
CO	NF	14.6	2.6	NF	12	15
CO_2	NF	36.5	–	14	42	32
Sulfur Species (ppmv)						
H_2S	NF	12,700	1450	82	3500	6000
COS	NF	110	–	NF	120	97
CH_3SH	NF	420	–	NF	460	590
C_2H_5SH	NF	220	–	NF	210	200
Hydrocarbons (vol %)						
C_2H_6	NF	0.22	–	Tr	0.42	0.47
C_2H_4	–	Tr	–	Tr	Tr	0.04
C_3's	NF	0.14	–	Tr	0.25	0.19
C_4's	NF	0.05	–	Tr	0.11	0.074
C_5's	NF	Tr	–	–	0.01	0.044
C_6^+	NF	0.12	–	NF	0.08	0.064
Aromatic Species (ppmv)						
Benzene	–	760	–	–	550	750
Toluene	–	220	–	–	100	230
Xylene and Ethylbenzene	–	75	–	–	38	100
Phenols	Tr	5.7	Tr	Tr	2.5	Tr
Nitrogen Species (ppmv)						
NH_3	NF	2400	690	340	NF	3.3
HCN	NF	600		54	170	320

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others
NF = Not Found, less than a trace
– = No Data Available

TABLE C.3-4. KOSOVO GAS PRODUCTION SECTION GASEOUS STREAM CARBON CONTENT DATA

	Carbon Content in g-atoms carbon per 100 moles of gas				
Species	Low Pressure Coal Lock Vent	Gas Liquor Tank Vent	Ash Lock Cyclone Vent	High Pressure Coal Lock Vent	Crude Product Gas
CH_4	8.6	-	Tr	11	12
CO	15	2.6	NF	12	15
CO_2	37	-	14	42	32
COS	0.011	-	-	0.012	0.0097
CH_3SH	0.042	-	NF	0.046	0.059
C_2H_5SH	0.044	-	NF	0.042	0.040
C_2H_6	0.44	-	Tr	0.84	0.94
C_2H_4	Tr	-	Tr	Tr	0.08
C_3's (as C_3H_8)	0.42	-	Tr	0.75	0.57
C_4's (as C_4H_{10})	0.20	-	Tr	0.44	0.30
C_5's (as C_5H_{12})	Tr	-	-	0.05	0.22
C_6^+ (as C_6H_{14})	0.72	-	NF	0.48	0.38
C_6H_6	0.46	-	-	0.33	0.45
C_7H_8	0.15	-	-	0.070	0.16
C_8H_{10}	0.060	-	-	0.030	0.08
Phenols (as C_6H_7O)	0.003	Tr	Tr	0.002	Tr
HCN	0.06	-	0.005	0.017	0.032
TOTAL	62	2.6	14	68	62

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others
NF = Not Found, less than a trace
– = No Data Available

were converted from volumetric units (m^3/hr) to mass units (kg/hr) using Equation 2. An example of this calculation is given in Section C2.0. The calculations to convert carbon content to carbon mass flow rate for gaseous streams were performed using Equation 3. Again, an example of these calculations is given in Section C2.0.

Table C.3-5 shows the sulfur content data for the Gas Production section gaseous streams. The sulfur mass flow rate for each stream was calculated using Equation 3.

Nitrogen content data for gaseous streams are given in Table C.3-6. In the Gas Production section, it is difficult to segregate molecular nitrogen (N_2) present due to air entrained during sampling from that actually generated in the process. In the gas liquor tank vent gas the N_2/O_2 ratio in the analysis is close to the 79/21 N_2/O_2 ratio for air. For this stream, molecular nitrogen was not included in these calculations. For all other gaseous streams, molecular nitrogen was included in the nitrogen mass balance calculations.

The nitrogen mass flow rate for each stream is calculated from the data in Table C.3-6 using Equation 3. For example, for the low pressure coal lock vent, the nitrogen content is 0.66 g-atoms nitrogen per 100 moles of gas and the nitrogen mass flow rate is:

$$\begin{array}{l}\text{L.P. Coal Lock Vent}\\ \text{Nitrogen Mass Flow}\end{array} = \frac{(0.0066)(14.0)}{23.5}\,(2.0\text{E}{+}01) = 7.9\text{E}{-}02 \text{ kg N/gasifier-hr}$$

Table C.3-7 shows the computed mass flow rates of nitrogen in the gaseous streams.

Data for the wastewater generated in the Gas Production section is shown in Table C.3-8. The flow rate was converted from volumetric units (m^3/hr) to mass units (g/hr) using the following equation:

$$M = V \cdot \rho \qquad (4)$$

where: M = mass flow (kg/gasifier-hr)
V = volumetric flow (m^3/hr)
ρ = density of the stream (kg/m^3)

For the gas production wastewater, the density was assumed to be the density of water at 30°C. Using this assumption and Equation 4, the mass flow rate is:

$$\begin{array}{l}\text{Wastewater}\\ \text{Mass}\\ \text{Flow Rate}\end{array} = \left(\frac{3.0 \text{ m}^3}{\text{hr}}\right)\left(\frac{9.9645\text{E}{+}02 \text{ kg}}{\text{m}^3 \text{ at } 30^\circ\text{C}}\right) = 3.0\text{E}{+}03 \text{ kg/gasifier-hr}$$

Since wastewater carbon data were not available for this stream, it was not included in the carbon mass balance. Sulfur in the wastewater was found to be primarily in the form of sulfate (SO_4^{-2}). The conversion from mg of sulfate/L to mass flow sulfur in kg/hr is found by the following:

TABLE C.3-5. KOSOVO GAS PRODUCTION SECTION GASEOUS STREAM SULFUR CONTENT DATA

	Sulfur Content in g-atoms Sulfur per 100 moles of gas				
Species	Low Pressure Coal Lock Vent	Gas Liquor Tank Vent	Ash Lock Cyclone Vent	High Pressure Coal Lock Vent	Crude Product Gas
H_2S	1.3	0.15	0.0082	0.35	0.60
COS	0.011	-	-	0.012	0.0097
CH_3SH	0.042	-	-	0.046	0.059
C_2H_5SH	0.022	-	-	0.021	0.020
TOTAL	1.4	0.15	0.0082	0.43	0.69

- = No Data Available

TABLE C.3-6. KOSOVO GAS PRODUCTOIN SECTION GASEOUS STREAM NITROGEN CONTENT DATA

Species	Nitrogen Content in g-atoms Nitrogen per 100 moles of gas				
	Low Pressure Coal Lock Vent	Gas Liquor Tank Vent	Ash Lock Cyclone Vent	High Pressure Coal Lock Vent	Crude Product Gas
NH_3	0.24	0.069	0.034	-	0.0002
HCN	0.06	-	0.0054	0.017	0.032
TOTAL (Excluding N_2)	0.30	0.069	0.039	0.017	0.032
N_2	0.36	*	70.00	0.28	1.3
TOTAL (Including N_2)	0.66	0.069	70.00	0.30	1.3

*N_2/O_2 ratio in Gas Liquor Tank Vent is 85/20, approximately the 79/21 N_2/O_2 ratio of air; therefore, not included.

- = No Data Available

TABLE C.3-7. NITROGEN MASS FLOW RATES IN KOSOVO GAS PRODUCTION SECTION GASEOUS STREAMS

Stream	All values in kg/gasifier-hr Excluding N_2 ($HCN + NH_3$ Only)	Including N_2 ($HCN + NH_3 + N_2$)
Low Pressure Coal Lock Vent	3.6 E-02	7.9 E-02
Gas Liquor Tank Vent*	1.9 E-02	1.9 E-02
Ash Lock Cyclone Vent	7.4 E-03	1.3 E+01
High Pressure Coal Lock Vent	2.2 E-02	3.9 E-01
Crude Product Gas	3.5 E+03	1.4 E+02

*See note for Table C.3-6.

TABLE C.3-8. FLOW RATE AND COMPOSITION DATA FOR KOSOVO GAS PRODUCTION SECTION WASTEWATER

Component	Value
Flow Rate (m^3/gasifier-hr)	3.0
Aqueous Composition Data (mg/L)	
Total Phenols	–
Volatile Phenols	0.17
Free Ammonia	Tr
Fixed Ammonia	1.9
Cyanide	0.01
Nitrites	0.40
Nitrates	4.8
Pyridines	–
Chlorides	28
Fluorides	0.91
Sulfites	Tr
Sulfates	495
Sulfides	Tr
Thiocyanates	0.26
Thiosulfates	Tr

Tr = Trace, <1.0 mg/L
– = No Data Available

$$M_S = C_{SO_4^{-2}} \left(\frac{MW_S}{MW_{SO_4^{-2}}}\right)\left(\frac{1\ g/m^3}{mg/L}\right)\left(\frac{1\ kg}{1000\ g}\right)V \tag{5}$$

where: M_S = mass flow sulfur in kg/gasifier-hr

$C_{SO_4^{-2}}$ = concentration of SO_4^{-2} in mg/L

MW_S, $MW_{SO_4^{-2}}$ = molecular weights of sulfur and sulfate, respectively

V = volumetric total stream flow in m^3/hr

For the wastewater, this calculation is:

$$\begin{array}{l}\text{Wastewater}\\ \text{Sulfur}\\ \text{Mass Flow}\end{array} = \left(\frac{495\ mg\ SO_4^{-2}}{L}\right)\left(\frac{32g\ S/gmole\ S}{96g\ SO_4/gmole\ SO_4^{-2}}\right)\left(\frac{1\ g/m^3}{mg/L}\right)\left(\frac{1\ kg}{1000\ g}\right)\left(\frac{3\ m^3}{hr}\right)$$

$$= 5.0E{-}01\ kg\ S/gasifier{-}hr$$

Nitrogen-containing species in the gas production wastewater are shown in Table C.3-9. The conversion from mg N/L to kg/hr is similar to the sulfur conversion (Equation 5). The nitrogen conversion is:

$$M_N = C_N \left(\frac{1\ g/m^3}{mg/L}\right)\left(\frac{1\ kg}{1000\ g}\right)V \tag{6}$$

where: M_N = mass flow of nitrogen in kg/gasifier-hr

C_N = concentration of nitrogen in mg/L

V = total volumetric stream flow in m^3/hr

Using the data in Table C.3-9, the wastewater nitrogen mass flow is:

$$\begin{array}{l}\text{Wastewater}\\ \text{Nitrogen}\\ \text{Mass Flow}\end{array} = \left(\frac{2.77\ mgN}{L}\right)\left(\frac{1\ g/m^3}{mg/L}\right)\left(\frac{1\ kg}{1000\ g}\right)\left(\frac{3\ m^3}{hr}\right)$$

The accountabilities given in Table C.3-1 were calculated using Equation 7:

$$\%\ \text{Accountability} = \frac{\Sigma\ \text{Outlet Streams}}{\Sigma\ \text{Inlet Streams}}\quad 100\% \tag{7}$$

TABLE C.3-9. NITROGEN-CONTAINING SPECIES IN KOSOVO GAS PRODUCTION SECTION WASTEWATER

Component	Component Concentration mg/L	Nitrogen Concentration mg/L
NH_3	1.9	1.56
HCN	0.01	0.005
Nitrites (as NO_2^-)	0.40	0.12
Nitrates (as NO_3^-)	4.8	1.08
TOTAL		2.77

For example, for carbon species in the gas production section, the mass flow of carbon leaving the section is:

Stream	Carbon Mass Flow (kg/hr)
Crude Product	5.7 E+03
Gasifier Ash	4.7 E+01
Wastewater	?
L.P. Coal Lock Vent	6.4 E+00
Gas Liquor Tank Vent	1.6 E+03
Ash Lock Cyclone Vent	2.3 E+00
H.P. Coal Lock Vent	1.6 E+02
TOTAL	5.9 E+03

The total inlet carbon mass flow rate is:

Stream	Carbon Mass Flow (kg/hr)
Dried Coal	7.1 E+03
Steam	*
Oxygen	*
TOTAL	7.1 E+03

*Assumed to be zero.

Then using Equation 10, the accountability is:

$$\text{\% Accountability of Carbon in Gas Production Section} = \frac{5.93\ E{+}03\ kg/hr}{7.12\ E{+}03\ kg/hr}\ 100\%$$

$$= 83\%$$

As Table C.3-1 shows, the accountability of nitrogen in the Gas Production section is low. This poor accountability is probably the result of two major factors:

- the difficulties associated with accounting for molecular nitrogen generation in the gasifier (as discussed above) and,
- a significant portion of the unaccounted nitrogen may be leaving this section in the gas liquors sent to the Tar/Oil Separation section (as ammonia or cyanide ions).

C4.0 MASS BALANCE CALCULATIONS FOR THE KOSOVO RECTISOL SECTION

Mass balance calculations for the Kosovo Rectisol section were performed for carbon, nitrogen, and sulfur. The results are shown in Table C.4-1. The major inlet and outlet streams in the Rectisol section include:

Inlet Streams:

- Crude Product Gas (from Gas Production)

Outlet Streams:

- Clean Product Gas
- By-Product Naphtha (to By-Product Storage)
- Gas Liquor (to Medium Oil Separator in Tar/Oil Separation)
- Cyanic Water (to Tar/Oil Separation)
- H_2S-Rich Waste Gas (to Flare System)
- CO_2-Rich Waste Gas

The gas liquor was not sampled during the test program, so it was not included in these calculations.

Table C.4-2 shows the flow rate and composition data for the by-product naphtha stream. Data for carbon, sulfur, and nitrogen were converted from concentration (wt %) to mass flow rate (kg/hr) using Equation 1. Cyanic water data are shown in Table C.4-3. Only a partial analysis was performed on this

TABLE C.4-1. KOSOVO RECTISOL SECTION MASS BALANCE RESULTS

Stream	Total Mass Flow	Carbon Mass Flow	Sulfur Mass Flow	Nitrogen Mass Flow
	All values in kg/gasifier-hr			
Inlet Streams:				
Crude Product Gas (g) (from Gas Production)	1.7 E+04	5.7 E+03	1.7 E+02	1.4 E+02
TOTAL INLET		5.7 E+03	1.7 E+02	1.4 E+02
Outlet Streams:				
By-Product Naphtha (ol) (to By-Product Storage)	1.3 E+02	1.1 E+02	2.8 E+00	2.3 E-01
Cyanic Water (aq) (to Tar/Oil Separation)	6.2 E+02	-	4.8 E-02	-
Clean Product Gas (g)	4.6 E+03	2.1 E+03	4.3 E-02	4.7 E+01
H_2S-Rich Waste Gas (g) (to Flare System)	6.3 E+03	1.8 E+03	2.3 E+02	4.9 E+00
CO_2-Rich Waste Gas (g)	6.2 E+03	1.8 E+03	5.4 E-01	3.7 E-02
TOTAL OUTLET		5.7 E+03	2.3 E+02	5.2 E+01
Accountability (%)		100	137	37

- = No Data Available

(g) - gaseous stream

(ol) - organic liquid stream

(aq) - aqueous stream

TABLE C.4-2. KOSOVO RECTISOL SECTION BY-PRODUCT NAPHTHA STREAM DATA

Component	Value
Flow Rate (kg/gasifier-hr)	1.3 E+02
Ultimate Analysis (wt%)	
Carbon	85.7
Hydrogen	9.9
Nitrogen	0.18
Sulfur	2.15
Oxygen	2.15

TABLE C.4-3. KOSOVO RECTISOL SECTION CYANIC WATER STREAM DATA

Component	Value
Flow Rate (m^3/gasifier-hr)	0.8
Temperature (°C)	80
Sulfur Content (mg/L)	60

stream. The flow rate for cyanic water was converted from volumetric units (m^3/hr) to mass units (kg/hr) using Equation 4.

Gaseous stream data are given in Table C.4-4. The gaseous stream flow rates were converted from volumetric units (m^3/hr) to mass units (kg/hr) using Equation 2. Carbon content data in Rectisol section gaseous streams are shown in Table C.4-5. The total carbon content for each gaseous stream was used to calculate the carbon mass flow with Equation 3. Sulfur and nitrogen data are given in Tables C.4-6 and C.4-7 respectively. These data were converted to mass flow using Equation 3.

In Section C3.0, it was noted that it was not possible, with the data available, to segregate the N_2 due to air entrained during sampling from that due to conversion of bound-nitrogen species in the gasifier or entering with the oxygen fed to the gasifiers. Since the inlet crude product gas comes from the Gas Production section, the same problem occurs in evaluating Rectisol gaseous streams. The results shown in Table C.4-1 include N_2. When N_2 is not included, the accountability of nitrogen in Rectisol increases from 37 to 150% (as calculated using Equation 7). However, no nitrogen data was available for the cyanic water stream, which should contain a significant amount of HCN and NH_3. Table C.4-8 shows the nitrogen mass flow rates for all Rectisol gaseous streams with and without N_2 included. The results from these Rectisol calculations indicate that at least a portion of the fixed nitrogen in the crude product gas was generated or entrained during the gasification process.

C5.0 MASS BALANCE CALCULATIONS FOR THE KOSOVO PHENOSOLVAN SECTION

Carbon, sulfur, and nitrogen mass balance calculations were performed for the Phenosolvan section. The results are shown in Table C.5-1. Major inlet and outlet streams in the Phenosolvan section include:

Inlet Streams:

- Phenolic Inlet Water (from Tar/Oil Separation)
- Steam Condensate

Outlet Streams:

- Wastewater
- Filter Backflush Water (to Tar Separators in the Tar/Oil Separation Section)
- Crude Phenol (to By-Product Storage)
- By-Product Ammonia (to By-Product Storage)
- Unclean Oil (to By-Product Storage)

TABLE C.4-4. KOSOVO RECTISOL SECTION GASEOUS STREAM DATA

	H_2S-Rich Waste Gas (Flare Feed)	CO_2-Rich Waste Gas Vent	Crude Product Gas	Clean Product Gas
Dry Gas Flow Rate (m^3/gasifier-hr at 25°C)	3,600	3,600	18,000	10,900
Molecular Wt. of Dry Gas	43.0	42.2	21.9	10.3
Composition (Dry Basis)				
Fixed Gases (vol %)				
H_2	0.11	Tr	38.1	60
O_2	Tr	Tr	0.36	0.44
N_2	Tr	Tr	0.64	0.38
CH_4	4.3	1.2	11.5	16
CO	1.1	Tr	15	22
CO_2	88	94	32	0.02
Sulfur Species (ppmv)				
H_2S	45,400	39	6,000	NF
COS	420	62	97	0.17
CH_3SH	2,100	8.5	590	1.1
C_2H_5SH	780	4.4	200	1.0
Hydrocarbons (vol %)				
C_2H_6	0.82	1.6	0.47	0.15
C_2H_4	Tr	Tr	0.04	Tr
C_3's	0.63	0.28	0.19	Tr
C_4's	0.32	Tr	0.074	Tr
C_5's	0.04	Tr	0.044	Tr
C_6^+	0.21	NF	0.064	0.03
Aromatic Species (ppmv)				
Benzene	110	1.0	750	-
Toluene	8	Tr	230	-
Xylene and Ethylbenzene	NF	Tr	100	-
Phenols	Tr	NF	Tr	Tr
Nitrogen Species (ppmv)				
NH_3	2,200	4.6	3.3	Tr
HCN	200	13	320	-

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

NF = Not Found, less than a trace

– = No Data Available

TABLE C.4-5. **KOSOVO RECTISOL SECTION GASEOUS STREAM CARBON CONTENT DATA**

Species	Carbon Content in g-atoms Carbon per 100 moles of H_2S-Rich Waste Gas	 CO_2-Rich Waste Gas	 Crude Product Gas	 Clean Product Gas
CH_4	4.3	1.2	11.5	16
CO	1.1	Tr	15	22
CO_2	88	94	32.3	0.02
COS	0.042	0.0062	0.0097	Tr
CH_3SH	0.21	0.0009	0.059	Tr
C_2H_5SH	0.156	0.0009	0.040	Tr
C_2H_6	1.64	3.20	0.94	0.30
C_2H_4	Tr	Tr	0.08	Tr
C_3's (as C_3H_8)	1.89	0.84	0.57	Tr
C_4's (as C_4H_{10})	1.28	Tr	0.296	Tr
C_5's (as C_5H_{12})	0.20	Tr	0.22	Tr
C_6^+ (as C_6H_{14})	1.26	–	0.384	0.18
C_6H_6	0.066	0.0006	0.45	–
C_7H_8	0.006	Tr	0.161	–
C_8H_{10}	–	Tr	0.08	–
Phenols (as C_6H_5OH)	Tr	–	Tr	Tr
HCN	0.020	0.0013	0.032	–
TOTAL	100	99	62	39

Tr = Trace, ~ 0.01 g-atoms for fixed gases, ~ 0.0001 for all others
– = No Data Available

TABLE C.4-6. KOSOVO RECTISOL SECTION GASEOUS STREAM SULFUR CONTENT

	Sulfur Content in g-atoms Sulfur per 100 moles of gas			
Species	H_2S-Rich Waste Gas	CO_2-Rich Waste Gas	Crude Product Gas	Clean Product Gas
H_2S	4.54	0.0039	0.60	–
COS	0.042	0.0062	0.0097	Tr
CH_3SH	0.21	0.0009	0.059	Tr
C_2H_5SH	0.078	0.0004	0.020	Tr
TOTAL	4.87	0.0114	0.689	0.0003

– = No Data Available
Tr = Trace, ~0.0001 g-atoms

TABLE C.4-7. KOSOVO RECTISOL SECTION GASEOUS STREAM NITROGEN CONTENT DATA

	Nitrogen Content in g-atoms Nitrogen per 100 moles of gas			
Species	H_2S-Rich Waste Gas	CO_2-Rich Waste Gas	Crude Product Gas	Clean Product Gas
NH_3	0.22	0.0005	0.0002	–
HCN	0.02	0.0013	0.032	–
N_2	Tr	Tr	1.3*	0.76*
TOTAL	0.24	0.0018	1.3	0.76

*See discussion in Section C2.0 on N_2 in Gas Production Section Streams.
– = No Data Available
Tr = Trace, ~0.0001 g-atoms

TABLE C.4-8. NITROGEN MASS FLOW RATES IN KOSOVO RECTISOL SECTION GASEOUS STREAMS

Stream	All values in kg/gasifier-hr Excluding N_2 ($HCN + NH_3$ Only)	 Including N_2 ($HCN + NH_3 + N_2$)
H_2S-Rich Waste Gas	4.9 E+00	4.9 E+00
CO_2-Rich Waste Gas	3.7 E-02	3.7 E-02
Crude Product Gas	3.5 E+00	1.4 E+02
Clean Product Gas	–	4.7 E+01

– = No Data Available

TABLE C.5-1. KOSOVO PHENOSOLVAN SECTION MASS BALANCE RESULTS

Stream	All values in kg/gasifier-hr			
	Total Mass Flow	Carbon Mass Flow	Sulfur Mass Flow	Nitrogen Mass Flow
Inlet Streams:				
Phenolic Inlet Water (aq) (from Tar/Oil Separation)	1.3 E+04	6.5 E+01	–	4.1 E+01
TOTAL INLET		6.5 E+01	–	4.1 E+01
Outlet Streams:				
Wastewater (aq)	1.3 E+04	1.9 E+01	1.1 E+00	2.2 E+00
Crude Phenol (ol) (to By-Product Storage)	9.0 E+01	–	–	–
Unclean Oil (ol) (to By-Product Storage)	3.0 E+01	2.5 E+01	2.5 E-01	3.0 E-01
Degassing Cyclone Vent (g)	2.6 E+00		6.0 E-03	1.0 E-03*
Ammonia Stripper Vent (g)	3.5 E+02	7.6 E+01	6.8 E+00	6.3 E+01
Cooler Vent (g)	5.9 E+00	–	–	–
2nd Degassing Vent (g)	5.2 E-01			1.8 E-02
Crude Phenol Tank Vent (g)	2.3 E-01	2.6 E-05	4.7 E-05	5.3 E-06*
DIPE Tank Vent (g)	6.5 E-01	–	–	1.6 E-05*
TOTAL OUTLET		1.2 E+03	8.1 E+00	6.3 E+01
Accountability (%)		180	–	155

* – Excluding molecular Nitrogen (N_2)

– = No Data Available

(g) – gaseous stream

(ol) – organic liquid stream

(aq) – aqueous stream

- Degassing Cyclone Vent Gas
- Gas Tank Vent Gas
- Unclean Oil Tank Vent Gas
- Phenolic Water Tank Vent Gas
- Ammonia Stripper (First Degassing) Vent Gas
- Cooler Vent Gas
- Second Degassing Vent Gas
- Slop Tank Vent Gas
- Crude Phenol Tank Vent Gas
- Diisopropyl Ether (DIPE) Tank Vent Gas

Inlet steam condensate was not included in these calculations. It is assumed that any contaminants in the steam are small compared to the inlet phenolic water. During the test program, by-product ammonia was not being collected, but was being discharged with the ammonia stripper vent gas. Therefore, the by-product ammonia stream was not included. No data was available for the filter backflush or the crude phenol streams. Therefore, these streams were not considered either.

While no analysis of the unclean oil was available, it was assumed that the composition of the unclean oil was the same as the composition of the medium oil by-product. Table C.5-2 presents data for the unclean oil. The concentration data shown (medium oil concentration data) were converted to mass flows using Equation 1.

Aqueous stream data for the inlet phenolic water and the Phenosolvan wastewater are given in Table C.5-3. The total organic carbon (TOC) values shown in Table C.5-3 were converted from concentration (mg/L) to carbon mass flow rate (kg/hr) using the following:

$$\left(M_c = C_c\right)\left(\frac{1\ g/m^3}{mg/L}\right)\left(\frac{1\ kg}{1000\ g}\right)V \qquad (8)$$

where: M_c = mass flow of carbon in kg/gasifier-hr

C_c = concentration of carbon in mg/L

V = volumetric stream flow rate in m^3/hr

TABLE C.5-2. KOSOVO PHENOSOLVAN SECTION UNCLEAN OIL DATA

Component	Value
Flow Rate (kg/gasifier-hr)	3.0 E+01
Ultimate Analysis of Medium Oil (wt %)	
Carbon	81.8
Hydrogen	8.94
Nitrogen	1.00
Sulfur	0.83
Ash	0.03
Oxygen (by Difference)	8.2

TABLE C.5-3. KOSOVO PHENOSOLVAN SECTION AQUEOUS STREAM DATA

Component	Inlet Water	Wastewater
Flow Rate (m^3/gasifier-hr)	>13	13
pH	9.2	9.6
Temperature (°C)	60	33
Aqueous Composition Data (mg/l)		
TOC	4970	1470
Total Phenols	2120	230
Volatile Phenols	–	130
Free Ammonia	3510	Tr
Fixed Ammonia	250	205
Cyanide	<1	0.019
Nitrites	–	Tr
Nitrates	<1	11.4
Chlorides	–	60
Fluorides	–	Tr
Total Sulfur	–	84
Sulfites	–	–
Sulfates	–	–
Sulfides	–	–
Thiocyanates	75	3.1
Thiosulfates	–	Tr
Pyridine	28	–
Methylpyridine's	42	–
Dimethyl- and Ethylpyridines	46	–
Alkylpyridines (as ethylpyridine)	26	–
Quinoline	5	–
Alkylquinolines (as ethylquinoline)	12	–

Tr = Trace, <1 mg/L for Free NH_4, Thiosulfate, <0.05 for Fluorides, ≤0.01 for Nitrite
– = No Data Available

For the inlet water, the carbon mass flow is:

$$\begin{array}{l}\text{Inlet Water}\\ \text{Carbon Mass}\\ \text{Flow Rate}\end{array} = \left(\frac{4970\ \text{mgC}}{\text{L}}\right)\left(\frac{1\ \text{g/m}^3}{\text{mg/L}}\right)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right)\ \frac{13\ \text{m}^3}{\text{hr}}\Bigg)$$

$$= 6.5\ \text{E+01 kg/gasifier-hr}$$

The total sulfur concentration in the wastewater is shown in Table 5-3. This value was converted to sulfur mass flow (kg/hr) using the following:

$$M_S = C_S \left(\frac{1\ \text{g/m}^3}{\text{mg/L}}\right)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right) V \qquad (9)$$

where: M_S = mass flow of sulfur in kg/gasifier-hr

C_S = concentration of sulfur in mg/L

V = volumetric stream flow rate in m^3/gasifier-hr

For the wastewater then, the sulfur mass flow is:

$$\begin{array}{l}\text{Wastewater}\\ \text{Sulfur Mass Flow}\end{array} = \left(\frac{84\ \text{mg S}}{\text{L}}\right)\left(\frac{1\ \text{gm}^3}{\text{mg/L}}\right)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right)\left(\frac{13\ \text{m}^3}{\text{hr}}\right)$$

$$= 1.1\ \text{E+00 kg/gasifier=hr}$$

Sulfur data were not available for the inlet water. Therefore, the sulfur mass balance around the Phenosolvan section is incomplete.

Table C.5-4 shows nitrogen content data for the Phenosolvan aqueous streams. The concentration data shown were converted to mass flow using Equation 6.

Gaseous stream data for the Phenosolvan section are shown in Table C.5-5. Flow rate data were not available for the gas tank vent, unclean oil tank vent, phenolic water tank vent, or slop tank vent so these streams were not included in the mass balance calculations. Carbon content data for gaseous streams are given in Table C.5-6. Flow rate and carbon species data were only available for the ammonia stripper vent and crude phenol tank vent streams. The calculations to obtain carbon mass flow from the concentration data in Table C.5-6 were performed using Equation 3.

Sulfur concentration data for Phenosolvan gaseous streams are given in Table C.5-7. Three streams were analyzed for both flow rate and sulfur-containing species. These are the degassing cyclone vent, ammonia stripper vent, and crude phenol tank vent. Table C.5-8 shows nitrogen concentration data for the Phenosolvan gaseous streams. Most of the gaseous streams in this section were analyzed for NH_3. In all cases except the ammonia stripper vent, the N_2/O_2 ratio for the gaseous data in Table C.5-5 is near the 79/21 N_2/O_2

TABLE C.5-4. KOSOVO PHENOSOLVAN SECTION AQUEOUS STREAM NITROGEN CONTENT DATA

Species	Nitrogen Content in mg N/L	
	Inlet Water	Wastewater
NH_3	3096	169
CN^-	Tr	0.01
Nitrites (as NO_2^-)	-	Tr
Nitrates (as NO_3^-)	Tr	2.6
Thiocyanates (as CNS)	18	0.75
Pyridine	5	-
Methylpyridine's	6	-
Dimethyl- and Ethylpyridine	6	-
Alkylpyridines (as $C_8H_{11}N$)	3	-
Quinoline	0.5	-
Alkylquinolines (as $C_{11}H_{11}N$)	1	-
TOTAL	3140	170

TABLE C.5-5. KOSOVO PHENOSOLVAN SECTION GASEOUS STREAM DATA

	Degassing Cyclone Vent	Ammonia Stripper Vent	Cooler Vent	2nd Degassing Vent	Crude Phenol Tank Vent	DIPE Tank Vent
Dry Gas Flow Rate (m^3/gasifier-hr at 25°C)	2.2	260	4.4	0.44	0.20	0.55
Molecular Wt. of Dry Gas	-	32.7	-	-	28.0	-
Composition (Dry Basis)						
Fixed Gases (vol %)						
H_2	-	NF	-	NF	NF	NF
O_2	-	-	-	21	20	21
N_2	-	-	-	78	77	79
CH_4	-	Tr	-	-	Tr	-
CO	-	NF	-	NF	NF	NF
CO_2	-	55	-	-	NF	-
Sulfur Species (ppmv)						
H_2S	2100	19,500	NF	NF	180	NF
COS	-	NF	-	-	NF	-
CH_3SH	-	290	-	-	NF	-
C_2H_5SH	-	100	-	-	NF	-
Hydrocarbons (vol %)						
C_2's	-	Tr	-	-	Tr	-
C_3's	-	Tr	-	-	Tr	-
C_4's	-	Tr	-	-	Tr	-
C_5's	-	Tr	-	-	Tr	-
C_6^+	-	NF	-	-	NF	-
Aromatic Species (ppmv)						
Benzene	-	Tr	-	-	-	-
Toluene	-	-	-	-	-	-
Xylene and Ethylbenzene	-	Tr	-	-	-	-
Phenols	NF	6,200	Tr	NF	22	Tr
Nitrogen Species (ppmv)						
NH_3	790	418,000	82,000	200	22	51
HCN	-	4,800	-	-	34	-

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

NF = Not Found, less than a trace

- = No Data Available

TABLE C.5-6. KOSOVO PHENOSOLVAN SECTION GASEOUS STREAM CARBON CONTENT DATA

Species	Carbon Content in g-atoms Carbon per 100 moles of gas	
	Ammonia Stripper Vent	Crude Phenol Tank Vent
CH_4	Tr	Tr
CO	NF	NF
CO_2	55	NF
COS	NF	–
CH_3SH	0.029	–
C_2H_5SH	0.010	–
C_2's (as C_2H_6)	Tr	Tr
C_3's (as C_3H_8)	Tr	Tr
C_4's (as C_4H_{10})	Tr	Tr
C_5's (as C_5H_{12})	Tr	Tr
C_6^+ (as C_6H_{14})	NF	NF
C_6H_6	Tr	–
C_7H_8	–	–
C_8H_{10}	Tr	–
Phenols (as C_6H_7O)	3.72	0.013
HCN	0.48	0.0034
TOTAL	59	0.027

Tr = Trace, ~0.01 vol % for CH_4, CO, CO_2 and ~1 ppmv (10^{-4} vol %) for all others
NF = Not Found, less than a trace
– = No Data Available

TABLE C.5-7. KOSOVO PHENOSOLVAN SECTION GASEOUS STREAM SULFUR CONTENT DATA

Species	Sulfur Content in g-atoms Sulfur per 100 moles of gas: Degassing Cyclone Vent	Ammonia Stripper Vent	Crude Phenol Tank Vent
H_2S	0.210	1.95	0.018
COS	-	NF	-
CH_3SH	-	0.029	-
C_2H_5SH	-	0.01	-
TOTAL	0.210	1.99	0.018

NF = Not Found

- = No Data Available

TABLE C.5-8. KOSOVO PHENOSOLVAN SECTION GASEOUS STREAM BOUND-NITROGEN CONTENT DATA

Species	Nitrogen Content in g-atoms Nitrogen per 100 moles of gas: Degassing Cyclone Vent	Ammonia Stripper Vent	Cooler Vent	2nd Degassing Vent	Crude Phenol Tank Vent	DIPE Tank Vent
NH_3	0.079	41.8	8.2	0.02	0.0012	0.0051
HCN	-	0.48	-	-	0.0034	-
TOTAL	0.079	42	8.2	0.02	0.0046	0.0051

- = No Data Available

ratio of air. Therefore, N_2 was not included in these calculations. Sulfur and nitrogen concentration data were converted to mass flow using Equation 3.

C6.0 KOSOVO FLARE SYSTEM CALCULATIONS

In the Phase II test program both the combined gas to flare (Stream 20.1) and the individual flare streams (3.6, 7.1, and 13.6) were analyzed. The combined gas to flare was analyzed to study the stream being combusted in the flare. Each of the individual flare feed streams were analyzed so that information about the individual process units could be obtained. The results obtained for these streams can be used to gain insight into the consistency of these independently determined measurements of waste gases to the flare.

The high pressure coal lock vent is an intermittent stream. The flow rate given for this stream is a time-phased average rate for an entire gasifier cycle. The combined gas-to-flare stream flow rate is also a time-phased average.

Mass balance results are shown in Table C.6-1. The conversion from volumetric concentration to mass flow was performed using Equation 3. Flow rate data were converted to mass flow (kg/hr) using Equation 2. As Table C.6-1 indicates, on a mass basis, the agreement between the individual stream analyses and the combined gas analysis is not very good. This difference is probably due to the fluctuation in the mass flow rates. Flow rate measurements being used in these mass balance calculations were performed on different days for each stream. Therefore, operational fluctuations at that time probably affected the results.

A more meaningful comparison is provided in Table C.6-2. In In this table, the component mass rate data in Table C.6-1 have been summed for the three individual flare feed streams and converted to concentration data using the total mass flow rate for three streams. The formula to convert from component mass flow to concentration is:

$$C_i = \left(\frac{M_i}{M_T}\right)\left(\frac{MW_T}{MW_i}\right) 100\% \qquad (10)$$

where: C_i = concentration of component i in vol%

M_i = mass flow of i in kg/hr

M_T = mass flow of total gas in kg/hr

MW_T = molecular weight of total gas

MW_i = molecular weight of i.

TABLE C.6.1. KOSOVO FLARE SYSTEM COMPARISON OF RESULTS (MASS BASIS)

	All values in kg/gasifier-hr					
Component	H.P. Coal Lock Vent	H_2S-Rich Waste Gas	Tar Separation Waste Gas	Total Sum	Combined Gas to Flare	Accountability* %
Total Dry Gas Flow Rate	2.3 E+02	6.3 E+03	6.2 E+00	6.6 E+03	2.3 E+03	35
H_2	6.0 E+00	3.3 E-01	3.5 E-02	6.4 E+00	1.1 E-02	0.17
O_2	7.2 E-01	4.7 E-01	5.1 E-04	1.2 E+00	1.7 E+00	150
N_2	3.7 E-01	4.1 E-01	4.5 E-04	1.1 E+00	3.2 E+00	280
CH_4	1.6 E+01	1.0 E+02	9,0 E-02	1.2 E+02	5.4 E+01	47
CO	3.2 E+01	4.5 E+01	4.9 E-02	7.7 E+01	2.9 E+01	38
CO_2	1.7 E+02	5.7 E+03	5.5 E+00	5.9 E+03	2.1 E+03	36
H_2S	1.1 E+00	2.3 E+02	4.9 E-02	2.3 E+02	2.0 E+01	7.1
COS	6.8 E-02	3.7 E+00	1.2 E-03	3.8 E+00	8.2 E-01	22
CH_3SH	2.1 E-01	1.5 E+01	1.9 E-02	1.5 E+01	6.5 E+00	44
C_2H_5SH	1.2 E-01	7.1 E+00	1.6 E-02	7.3 E+00	6.4 E-01	8.8
C_2H_6	1.2 E+00	3.6 E+01	1.6 E-02	3.7 E+01	1.2 E+01	32
C_2H_4	2.6 E-04	4.1 E-03	4.5 E-06	4.4 E-03	1.5 E-03	35
C_3's	1.0 E+00	4.1 E+01	2.9 E-02	4.2 E+01	1.6 E+01	38
C_4's	6.0 E-01	2.7 E+01	3.8 E-02	2.8 E+01	1.0 E+01	36
C_5's	6.8 E-02	4.2 E+00	1.0 E-02	4.3 E+00	1.6 E+00	36
C_6^+	6.5 E-01	2.7 E+01	1.8 E-01	2.7 E+01	4.7 E+00	17
C_6H_6	4.0 E-01	1.3 E+00	1.2 E-01	1.8 E+00	2.7 E+00	150
C_7H_6	8.7 E-02	1.1 E-01	1.8 E-02	2.1 E-01	1.1 E+00	510
C_8H_{10}	3.8 E-02	NF	2.6 E-03	4.1 E-02	1.9 E-01	470
Phenols	2.2 E-03	NF	6.3 E-05	2.3 E-03	5.1 E-03	230
NH_3	NF	5.5 E+00	5.3 E-02	5.6 E+00	NF	–
HCN	4.3 E-02	7.9 E-01	2.8 E-04	8.4 E-01	1.5 E-01	18

$$\text{*Accountability} = \frac{\text{Combined Gas to Flare}}{\text{Total Sum}} \quad 100\%$$

NF = Not Found

TABLE C.6-2. KOSOVO FLARE SYSTEM COMBINED GAS COMPOSITION COMPARISON OF RESULTS

Species	Calculated*	Measured
Flow Rate (m^3/gasifier-hr at 25°C)	3,870	1,330
Composition (Dry Basis)		
Fixed Gases (vol %)		
H_2	2.1	Tr
O_2	0.02	0.10
N_2	0.03	0.21
CH_4	4.6	6.2
CO	1.8	1.9
CO_2	85	88
Sulfur Species (ppmv)		
H_2S	42,700	10,600
COS	400	250
CH_3SH	2,000	2,500
C_2H_5SH	750	190
Hydrocarbons (vol %)		
C_2H_6	0.79	0.74
C_2H_4	Tr	Tr
C_3's	0.60	0.66
C_4's	0.31	0.32
C_5's	0.04	0.04
C_6^+	0.20	0.10
Aromatic Species (ppmv)		
Benzene	150	640
Toluene	15	215
Xylenes and Ethylbenzene	2.4	33
Phenols	Tr	Tr
Nitrogen Species (ppmv)		
NH	2,100	NF
HCN	200	100

*Calculated using Equation 10 from 'Total Sum' column data on Table 6-1.

Tr = Trace, ~0.01 vol. % for fixed gases, ~1 ppmv for all other species.

For example, for CO_2, the total mass flow of CO_2 in the high pressure coal lock vent gas (1.7 E+02 kg/hr), H_2S-rich waste gas (5.7 E+03 kg/hr), and tar separation waste gas (5.5 E+00 kg/hr) is 5.9 E+03 kg/hr. The conversion to concentration is:

$$\text{Vol\% } CO_2 = \left(\frac{5.9\text{ E+03}}{6.6\text{ E+03}}\right)\left(\frac{41.9}{44.01}\right) \quad 100\% = 85$$

Examination of the results shown in Table C.6-2 indicates that, for most species, the concentration data derived from the individual stream data correlate well with the data derived from measurement of the combined gas to flare.

C7.0 OVERALL (PLANT-WIDE) KOSOVO MASS BALANCE CALCULATIONS

Overall (plant-wide) mass balances were developed for carbon, sulfur, and nitrogen. The major inlet and outlet streams considered in performing the calculations necessary to arrive at overall mass balances are shown in Table C.7-1. The results from the overall mass balances are shown in Table C.7-2.

Most of the streams shown in Table C.7-1 were discussed in the individual plant section mass balance sections (C2.0 through C6.0). In this section, only those streams not discussed previously will be dealt with in detail. As in the plant section balances, it was assumed that the carbon, nitrogen, and sulfur entering the system in the steam stream is small compared to the amounts in the entering coal and oxygen streams. It was also assumed that the amount of methanol and DIPE not recovered for the stripping processes in which they are used (makeup requirements) is small. No data was available to verify this assumption as measurement of these streams was beyond the scope of the test program.

The two sections which have not been discussed previously are Tar/Oil Separation and By-Product Storage. One solid stream is generated in these sections. Data for that stream, heavy tar, are shown in Table C.7-3. Also shown in Table C.7-3 are data for the by-products which leave the By-Product Storage section: light tar, medium oil, and naphtha. For the unclean oil, the medium oil analysis was used. No data were available for the crude phenol, so it was not included in this balance. By-product ammonia was not being collected during the test program so it was also excluded. The heavy tar and by-products concentration data shown in Table C.7-3 were converted to component (carbon, nitrogen, and sulfur) mass flow rates using Equation 1.

Gaseous stream data for the Tar/Oil Separation and By-Product Storage sections are shown in Table C.7-4. Flow rate data were not available for the unpure tar tank and unpure oil tank so they were not included in this balance. Carbon content data for gaseous streams in the Tar/Oil Separation and By-Product Storage sections are given in Table C.7-5. The calculations to convert the concentration data given in Table C.7-5 to carbon mass flow rates were performed using Equation 3.

TABLE C.7-1. INLET AND OUTLET STREAMS USED IN OVERALL MASS BALANCE CALCULATIONS

Plant Section	Stream Description	State
Inlet Streams		
Coal Preparation	'Run-of-Mine' Coal	s
	Steam	g
Gas Production	Oxygen	g
Outlet Streams		
Coal Preparation	Fleissner Condensate	aq
	Feissner Autoclave Vent Gas	g
	Condensate Tank Vent Gas	g
Gas Production	Gasifier Ash	s
	Gas Production Wastewater	aq
	Dedusting Cyclone Vent Gas	g
	Low Pressure Coal Lock Vent Gas	g
	Ash Cylcone Vent Gas	g
Rectisol	Clean Product Gas	g
	CO_2-Rich Waste Gas	g
Tar/Oil Separation	Heavy Tar	s
	Tar Tank Vent Gas	g
	Medium Oil Tank Vent Gas	g
	Condensate Tank Vent Gas	g
	Phenolic Water Tank Vent Gas	g

(Continued)

TABLE C.7-1. (Continued)

Plant Section	Stream Description	State
Outlet Streams		
Phenosolvan	Phenosolvan Wastewater	aq
	Degassing Cyclone Vent Gas	g
	Ammonia Stripper (1st Degassing) Vent Gas	g
	Cooler Vent Gas	g
	2nd Degassing Vent Gas	g
	Crude Phenol Tank Vent Gas	g
	DIPE Tank Vent Gas	g
By-Product Storage	By-Product Light Tar	ol
	By-Product Medium Oil	ol
	By-Product Naphtha	ol
	Crude Phenol	ol
	Unclean Oil	ol
	Light Tar Storage Tank Vent Gas	g
	Medium Oil Storage Tank Vent Gas	g
	Naphtha Storage Tank Vent Gas	g
	Phenol Storage Tank Vent Gas	g

(Continued)

TABLE C.7-1. (Continued)

Plant Section	Stream Description	State
Outlet Streams		
Flare System	Combined Gas to Flare (high pressure coal lock vent gas, H_2S-rich waste gas, and tar/oil separation waste gas)	g

s - solid

g - gaseous

aq - aqueous

ol - organic liquid

TABLE C.7-2. KOSOVO OVERALL MASS BALANCE RESULTS

Stream	All values in kg/gasifier-hr			
	Total Mass Flow	Carbon Mass Flow	Sulfur Mass Flow	Nitrogen Mass Flow
Inlet Streams:				
Run-of-Mine Coal (s)	2.4 E+04	7.1 E+03[a]	1.4 E+02[a]	1.8 E+02[a]
Oxygen	2.8 E+03	–	–	9.9 E+01
TOTAL INLET		7.1 E+03	1.4 E+02	2.8 E+02
Outlet Streams:				
Autoclave Vent Gas (g)	7.9 E+01	8.5 E+00[c]	6.0 E-01[c]	–[b,c]
Gasifier Ash (s)	2.7 E+03	4.7 E+01	2.4 E+00	8.1 E-01
Gas Production Wastewater (aq)	2.6 E+03	–	5.0 E-01	8.3 E-03
Dedusting Cyclone Vent Gas (g)	8.4 E+03	0.[c,d]	0.[c,d]	0.[c,d]
L.P. Coal Lock Vent Gas (g)	2.0 E+01	6.4 E+00[c]	3.7 E-01[c]	7.9 E-02[c]
Ash Cyclone Vent Gas (g)	4.2 E+01	2.3 E+00[c]	3.5 E-03[c]	1.3 E+01[c]
Gas Liquor Tank Vent Gas (g)	4.5 E+01	5.9 E-01	8.8 E-01	1.9 E-02[e]
Clean Product Gas (g)	4.6 E+03	2.1 E+03	4.3 E-02	4.7 E+01
CO_2-Rich Waste Gas (g)	6.2 E+03	1.8 E+03	5.4 E-01	3.7 E-02
Heavy Tar (s)	1.0 E+02	5.6 E+01	3.3 E-01	8.8 E-01

(Continued)

TABLE C.7-2. (Continued)

Stream	All values in kg/gasifier-hr			
	Total Mass Flow	Carbon Mass Flow	Sulfur Mass Flow	Nitrogen Mass Flow
Outlet Streams:				
Tar Tank Vent Gas (g)	6.1 E-01	1.4 E-02	5.1 E-03	7.9 E-04
Medium Oil Tank Vent Gas (g)	2.3 E+00	7.8 E-01	7.4 E-02	7.5 E-05[f]
Condensate Tank Vent Gas (g)	3.7 E+00	2.2 E-01	2.8 E-02	3.3 E-04[f]
Phenolic Water Tank Vent Gas (g)	7.7 E+00	1.5 E+00	1.6 E-01	3.8 E-02[f]
Phenosolvan Wastewater (aq)	1.3 E+04	1.9 E+01	1.1 E+00	2.2 E+00
Degassing Cyclone Vent (g)	2.6 E+00	–	6.0 E-03	1.0 E-03[g]
Ammonia Stripper Vent Gas (g)	3.5 E+02	7.6 E+01	6.8 E+00	6.3 E+01
Cooler Vent Gas (g)	5.9 E+00	–	–	–
2nd Degassing Vent Gas (g)	5.2 E-01	–	–	1.8 E-02[g]
Crude Phenol Tank Vent Gas (g)	2.3 E-01	2.6 E-05	4.7 E-05	5.3 E-06[g]
DIPE Tank Vent Gas (g)	6.5 E-01	–	–	1.6 E-05[g]
By-Product Light Tar (ol)	4.0 E+02	3.3 E+02	2.0 E+00	5.2 E+00
By-Product Medium Oil (ol)	2.5 E+02	2.1 E+02	2.1 E+00	2.5 E+00

(Continued)

TABLE C.7-2. (Continued)

Stream	All values in kg/gasifier-hr			
	Total Mass Flow	Carbon Mass Flow	Sulfur Mass Flow	Nitrogen Mass Flow
Outlet Streams:				
By-Product Naphtha (ol)	1.3 E+02	1.1 E+02	2.8 E+00	2.3 E-01
Crude Phenol (ol)	9.0 E+01	ND	ND	ND
Unclean Oil (ol)	3.0 E+01	2.5 E+01[i]	2.5 E-01[i]	3.0 E-01[i]
Light Tar Storage (g) Tank Vent Gas	6.5 E-01	1.6 E-05	6.4 E-04	3.1 E-05[f]
Medium Oil Storage (g) Tank Vent Gas	3.2 E-01	8.0 E-07	5.7 E-04	1.2 E-05
Naphtha Storage (g) Tank Vent Gas	6.1 E+00	1.3 E+00	7.2 E-02	2.8 E-03[f]
Phenol Storage (g) Tank Vent Gas	1.0 E-01	2.6 E-07	0.	2.0 E-07[f]
Combined Gas to Flare (g)	6.6 E+03	1.8 E+03[j,c]	2.3 E+02[j,c]	7.5 E+00[j,c]
TOTAL OUTLET		6.5 E+03	2.5 E+02	1.4 E+02
Accountability (%)[j]		92	180	51

(Continued)

TABLE C.7-2. (Continued)

NOTES:

[a] C, S, and N values in wet coal were calculated from the Coal Preparation outlet streams by mass balance.

[b] Excluding all molecular nitrogen. See Section 2.0 for discussion.

[c] Does not include particulate data - no analysis available.

[d] Amounts of C, S, and N in Dedusting Cyclone Vent negligible; this stream has a significant particulate loading.

[e] Molecular nitrogen in excess of (79/21) x O_2 (vol %) included. See Section 3.0 for discussion.

[f] All fixed molecular nitrogen excluded. See discussion in this section.

[g] Excluding all molecular fixed nitrogen. See Section 5.0 for discussion.

[h] Unclean Oil mass flows were calculated using analysis data for the By-Product Medium Oil. See Section 5.0 for discussion.

[i] Combined Gas to Flare calculated using Equation 3 and data in Table 6-2, 'calculated' column See Section 6.0 for discussion.

[j] Accountabilities calculated using Equation 7. See Section 3.0.

- = No Data Available.

( ) - Stream Type - s = solid, ol = organic liquid, aq = aqueous, g = gaseous.

TABLE C.7-3. DATA FOR KOSOVO HEAVY TAR AND BY-PRODUCTS

Component	Heavy Tar	Light Tar	Medium Oil	Naphtha
Flow Rate (kg/gasifier-hr)	1.0 E+02	4.0 E+02	2.5 E+02	1.3 E+02
Ultimate Analysis (wt %)				
Carbon	56.0	81.9	81.8	85.7
Hydrogen	7.6	8.4	8.9	9.9
Nitrogen	0.87	1.3	1.0	0.2
Sulfur	0.33	0.49	0.83	2.2
Ash	6.6	0.22	0.03	–
Oxygen	28.6	7.8	8.2	2.1

– = No Data Available

TABLE C.7-4. KOSOVO TAR/OIL SEPARATION AND BY-PRODUCT STORAGE SECTIONS GASEOUS STREAM DATA

Component	Tar/Oil Separation Streams						By-Product Storage Streams			
	Tar Tank Vent	Vapors Tar Tank Vent	Medium Oil Tank Vent	Vapors Oil Tank Vent	Condensate Tank Vent	Phenolic Water Tank Vent	Light Tar Storage Tank Vent	Medium Oil Storage Tank Vent	Naphtha Storage Tank Vent	Phenol Storage Tank Vent
Dry Gas Flow Rate (m^3/gasifier-hr at 25°C)	0.55	–	1.7	–	3.38	5.5	0.33	0.27	4.5	0.09
Molecular Wt. of Dry Gas	29.1	–	32.3	–	26.6	34.4	28.8	28.3	33.3	28.6
Composition (Dry Basis)										
Fixed Gases (vol %)										
H_2	Tr	NF	Tr	NF	14.6	Tr	NF	NF	NF	NF
O_2	19	20.3	0.45	27.2	16.6	11	19	6.2	2.6	16
N_2	77.5	78.2	1.1	75	61.0	33	81	88	84	84
CH_4	0.16	–	7.4	–	1.2	0.2	–	–	NF	–
CO	Tr	0.2	5.9	NF	NF	NF	NF	NF	NF	NF
CO_2	0.86	–	56	–	6.2	35	–	–	0.05	–
Sulfur Species (ppmv)										
H_2S	6900	430	26,000	1500	6200	12,600	890	1550	NF	NF
COS	110	–	96	–	–	41	–	–	NF	–
CH_3SH	390	–	5,200	–	210	2,100	–	–	2,600	–
C_2H_5SH	240	–	2,100	–	72	7,200	–	–	9,700	–
Hydrocarbons (vol %)										
C_2H_6	Tr	–	0.34	–	0.07	0.02	–	–	Tr	–
C_2H_4	–	–	Tr	–	–	–	–	–	–	–
C_3's	0.01	–	0.30	–	0.03	0.02	–	–	0.01	–
C_4's	Tr	–	0.25	–	0.03	0.02	–	–	0.07	–
C_5's	Tr	–	0.09	–	0.04	0.006	–	–	0.08	–
C_6^+	0.37	–	2.4	–	–	1.8	–	–	5.3	–
Aromatic Species (ppmv)										
Benzene	3000	–	7,650	–	3200	11,000	–	–	37,600	–
Toluene	960	–	1,400	–	3000	2,300	–	–	1,900	–
Xylene and Ethylbenzene	220	–	140	–	–	200	–	–	60	–
Phenols	57	Tr	110	NF	Tr	Tr	Tr	Tr	Tr	Tr
Nitrogen Species (ppmv)										
NH_3	2600	220	19	140	NF	12,000	100	75	NF	3.7
HCN	130	–	57	–	170	38	–	–	1,100	–

Tr = Trace, ~0.01 vol % for fixed gases and ~1 ppmv for all others

NF = Not Found, less than a trace

– = No Data Available

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TABLE C.7-5. KOSOVO TAR/OIL SEPARATION AND BY-PRODUCT STORAGE SECTIONS GASEOUS STREAM CARBON CONTENT DATA

Species	Carbon Content in g-atoms Carbon per 100 moles of gas							
	Tar Tank Vent	Medium Oil Tank Vent	Condensate Tank Vent	Phenolic Water Tank Vent	Light Tar Storage Tank Vent	Medium Oil Storage Tank Vent	Naphtha Storage Tank Vent	Phenol Storage Tank Vent
CH_4	0.16	7.6	1.19	0.2	-	-	NF	-
CO	0.01	5.9	NF	NF	NF	NF	NF	NF
CO_2	0.86	56	6.15	35	-	-	0.85	-
COS	0.011	0.0096	-	0.0041	-	-	NF	NF
CH_3SH	0.039	0.52	0.021	0.21	-	-	0.26	-
C_2H_5SH	0.048	0.42	0.0072	1.44	-	-	1.94	-
C_2's (as C_2H_6)	0.0002	0.68	0.14	0.04	-	-	0.0002	-
C_3's (as C_3H_8)	0.03	0.90	0.15	0.06	-	-	0.03	-
C_4's (as C_4H_{10})	0.0004	1.00	0.12	0.08	-	-	0.28	-
C_5's (as C_5H_{12})	0.0005	0.45	0.20	0.03	-	-	0.40	-
C_6^+ (as C_6H_{14})	2.22	14.4	-	10.8	-	-	31.8	-
C_6H_6	1.20	4.59	3.12	6.60	-	-	22.56	-
C_7H_8	0.672	0.98	2.10	1.61	-	-	1.33	-
C_8H_{10}	0.176	0.112	-	0.224	-	-	0.048	-
Phenols (as C_6H_7O)	0.034	0.066	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
HCN	0.013	0.0057	0.017	0.0038	-	-	0.11	-
TOTAL	5.5	94	13	56	0.0006	0.0006	60	0.0006

NF = Not Found

- = No Data Available

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Sulfur concentration data in gaseous streams for the Tar/Oil Separation and By-Product Storage sections are presented in Table C.7-6. These data were converted to sulfur mass flow rates using Equation 3.

Table C.7-7 shows nitrogen concentration data for gaseous streams in the Tar/Oil Separation and By-Product Storage sections. The total nitrogen values shown are corrected for air present over the liquid in the tanks. Even with corrections for air, the molecular nitrogen content in the storage tanks appears to be high if it is due to conversion of bound nitrogen during combustion or entrainment. Nowhere else in the plant are molecular nitrogen concentrations as high as those in the storage tanks. It is assumed that nitrogen was being used as a blanket for the volatile organic liquids to prevent combustion. Therefore, the molecular nitrogen values were excluded in these mass balance calculations. Nitrogen concentration values were converted to nitrogen mass flow rates using Equation 3.

For the combined gas to flare, the total mass flows calculated from measurements of the high pressure coal lock vent, H_2S-rich waste gas, and tar separation waste gas were used.

C8.0 KOSOVO OVERALL (PLANT-WIDE) TRACE ELEMENT MASS BALANCE CALCULATIONS

Atomic absorption spectrometry (AA) trace element data were used in overall (plant-wide) mass balance calculations for the Kosovo plant. The streams for which AA trace element data were obtained are:

- Dried Coal,
- Fleissner Condensate,
- Gasifier Ash,
- Heavy Tar,
- Light Tar,
- Medium Oil,
- Naphtha,
- Phenosolvan (Phenolic) Inlet Water,
- L.P. Coal Lock Vent Gas, and
- Combined Gas to Flare

No trace element data for the run-of-mine coal were obtained. Therefore, an overall balance including the coal drying section was not possible. The results shown in Table C.8-1 are for a balance of the gasification plant excluding the Coal Drying section. The data used in these mass balance

TABLE C.7-6. KOSOVO TAR/OIL SEPARATION AND BY-PRODUCT STORAGE SECTIONS GASEOUS STREAM SULFUR CONTENT DATA

Species	Sulfur Content in g-atoms Sulfur per 100 moles of gas							
	Tar Tank Vent	Medium Oil Tank Vent	Condensate Tank Vent	Phenolic Water Tank Vent	Light Tar Storage Tank Vent	Medium Oil Storage Tank Vent	Naphtha Storage Tank Vent	Phenol Storage Tank Vent
H_2S	0.69	2.60	0.62	1.26	0.089	0.155	NF	NF
COS	0.011	0.0096	-	0.0041	-	-	NF	-
CH_3SH	0.039	0.52	0.0021	0.21	-	-	0.26	-
C_2H_5SH	0.024	0.21	0.00072	0.72	-	-	0.97	-
TOTAL	0.764	3.34	0.623	2.19	0.089	0.155	1.23	NF

NF = Not Found
 - = No Data Available

TABLE C.7-7. KOSOVO TAR/OIL SEPARATION AND BY-PRODUCT STORAGE SECTIONS GASEOUS STREAM NITROGEN CONTENT DATA

	Nitrogen Content in g-atoms Nitrogen per 100 moles of gas							
Species	Tar Tank Vent	Medium Oil Tank Vent	Condensate Tank Vent	Phenolic Water Tank Vent	Light Tar Storage Tank Vent	Medium Oil Storage Tank Vent	Naphtha Storage Tank Vent	Phenol Storage Tank Vent
N_2	155	15.2	122	78	162	176	168	168
N_2 excluding air*	12.0	6.9	0	0	19	129	148	47.6
NH_3	0.26	0.0019	NF	1.2	0.01	0.0075	NF	0.0004
HCN	0.013	0.0057	0.017	0.0038	-	-	0.11	-
Total excluding air	12	6.9	0.017	1.2	19	130	150	48
Total excluding N_2	0.27	0.0076	0.017	1.2	0.01	0.0075	0.11	0.0004

*N_2 excluding air = N_2 - 79/21 O_2.
- = No Data Available

TABLE C.8-1. MASS BALANCE RESULTS FOR TRACE ELEMENTS IN KEY KOSOVO STREAMS ANALYZED BY ATOMIC ABSORPTION SPECTROMETRY

	All Values in kg/gasifier-hr									
	Inlet Stream	Outlet Streams								
Trace Element	Dried Coal	Gasifier Ash	Heavy Tar	Light Tar	Medium Oil	Naphtha	Phenosolvan Inlet Water	L.P. Coal Lock Vent	Combined Gas to Flare	Percentage of Amount Found in Dried Coal Accounted for in the Outlet Streams Given in this Table
As	9.4 E-01	2.0 E-01	1.6 E-03	6.8 E-03	5.0 E-04	8.5 E-05	1.3 E-03	3.6 E-05	2.5 E-06	22
Be	1.6 E-02	6.8 E-03	2.9 E-05	3.6 E-05	NF	2.7 E-07	NF	8.4 E-08	2.3 E-07	43
Cd	6.4 E-02	1.9 E-01	3.7 E-04	2.6 E-04	1.9 E-05	1.2 E-07	1.8 E-05	5.7 E-07	3.2 E-07	298
Co	5.4 E-02	4.6 E-02	1.5 E-04	NF	NF	7.7 E-07	NF	1.0 E-07	2.3 E-07	85
Cr	1.4 E+00	4.9 E-01	3.0 E-03	1.2 E-03	1.0 E-03	1.5 E-05	3.0 E-04	5.7 E-06	NF	35
Cu	6.9 E-01	1.1 E-01	6.0 E-04	6.4 E-03	2.8 E-04	2.4 E-05	1.4 E-04	3.8 E-06	7.7 E-06	17
Hg	1.2 E-02	8.2 E-04	6.4 E-05	NF	5.2 E-05	2.0 E-05	1.8 E-03	1.1 E-06	NF	23
Mo	1.0 E-01	2.4 E-02	8.5 E-05	NF	4.8 E-05	1.4 E-06	NF	9.5 E-07	NF	24
Ni	2.4 E+00	8.6 E-01	2.1 E-03	3.6 E-03	NF	2.1 E-05	1.7 E-04	2.5 E-06	1.0 E-05	36
Pb	1.3 E-01	1.4 E-01	6.4 E-03	2.7 E-03	3.5 E-04	9.8 E-06	1.8 E-04	1.5 E-06	1.3 E-06	115
Sb	NF	NF	3.9 E-04	NF	NF	1.9 E-06	NF	NF	NF	-
Se	3.2 E-01	6.5 E-02	2.6 E-04	6.4 E-04	4.8 E-04	1.1 E-04	6.5 E-04	-	9.6 E-06	21
Sr	3.0 E+00	1.0 E+00	4.1 E-03	8.0 E-03	2.2 E-03	NF	1.3 E-03	1.3 E-05	5.9 E-06	34
Tl	NF	NF	NF	NF	NF	NF	NF	NF	NF	-
V	2.2 E-01	2.7 E-01	5.7 E-04	NF	NF	NF	NF	1.9 E-07	9.0 E-07	123
Zn	2.2 E+00	5.7 E-03	9.8 E-03	1.1 E-02	3.8 E-03	2.1 E-05	3.6 E-03	3.4 E-05	4.1 E-05	1.5

NF = Not Found

- = No Data Available

calculations are shown in Table C.8-2. Trace element mass flows for the Fleissner condensate were not calculated because flow rate data were not available. The concentration data shown in Table C.8-2 were converted to elemental mass flow rate data. For solid streams (dried coal, gasifier ash, and heavy tar), the following formula was used:

$$M_i = C_i \left(\frac{1\ \text{kg}}{10^6\ \text{mg}}\right) M_T \qquad (11)$$

where: M_i = mass flow rate of element i in kg/gasifier-hr

C_i = concentration of element i in mg/kg

M_T = total stream flow rate in kg/gasifier-hr

For example, for the mass flow rate of As in dried coal, the calculation is:

$$\begin{array}{l}\text{Dried Coal} \\ \text{As Mass} \\ \text{Flow}\end{array} = \left(\frac{59\ \text{mg As}}{\text{kg coal}}\right)\left(\frac{1\ \text{kg As}}{10^6\ \text{mg As}}\right)\left(\frac{1.6\ \text{E+04 kg coal}}{\text{gasifier-hr}}\right)$$

$$= 9.4\text{E-01 kg As/gasifier}$$

For liquids by-products (light tar, medium oil, and naphtha), the following was used:

$$M_i = C_i \left(\frac{1\ \text{g}}{1000\ \text{mg}}\right) \frac{M_T}{\rho_T} \qquad (12)$$

where: M_i = mass flow rate of element i in kg/gasifier-hr

C_i = concentration of element i in mg/L

ρ_T = density of the stream in g/L

M_T = total stream flow rate in kg/gasifier-hr

Density data for the by-products are shown in Table C.8-3. These data were used for calculations to determine trace element mass flows in by-product streams. For example, the mass flow of As in light tar is:

$$\begin{array}{l}\text{Light Tar As} \\ \text{Mass Flow}\end{array} = \left(\frac{8.3\text{E+01 mg}}{\text{L}}\right)\left(\frac{1\ \text{g}}{1000\ \text{mg}}\right)\left(\frac{4.0\text{E+02 kg/hr}}{1059\ \text{g/L}}\right)$$

$$= 5.0\ \text{E-04 kg As/gasifier-hr}\ .$$

TABLE C.8-2. DATA FOR TRACE ELEMENTS IN KEY KOSOVO STREAMS ANALYZED BY ATOMIC ABSORPTION SPECTROMETRY

	Solids			By-Products			Waters		Gases	
Trace Element	Dried Coal (mg/kg)	Gasifier Ash (mg/kg)	Heavy Tar (mg/kg)	Light Tar (mg/l)	Medium Oil (mg/l)	Naphtha (mg/l)	Phenosolvan Inlet Water (mg/l)	Fleissner Condensate (mg/l)	L.P. Coal Lock Vent (µg/m³)	Combined Gas to Flare (µg/m³)
As	5.9 E+01	7.5 E+01	1.6 E+01	1.8 E+01	1.9 E+00	5.5 E-01	1.0 E-01	8.5 E-01	1.7 E+03	1.9 E+00
Be	1.0 E+00	2.5 E+00	2.9 E-01	1.0 E-01	NF-02	1.8 E-03	NF	5.0 E-03	4.0 E+00	NF
Cd	4.0 E+00	6.9 E+01	3.7 E+00	7.0 E-01	7.5 E-02	8.0 E-04	1.4 E-03	2.4 E-03	3.7 E+01	2.4 E-01
Co	3.4 E+00	1.7 E+01	1.5 E+00	NF	1.9 E-01	5.0 E-03	NF	2.2 E-03	4.9 E+00	1.7 E-01
Cr	8.7 E+01	1.8 E+02	3.0 E+01	3.2 E+00	3.9 E+00	1.0 E-01	2.3 E-02	2.5 E-01	2.7 E+02	NF
Cu	4.3 E+01	4.0 E+01	6.0 E+00	1.7 E+02	1.1 E+00	1.5 E-01	1.1 E-02	5.0 E-03	1.8 E+02	5.8 E+00
Hg	7.4 E-01	3.0 E-01	6.4 E-01	NF	2.0 E-01	1.3 E-01	1.4 E-01	8.0 E-02	5.3 E+01	NF
Mo	6.4 E+00	8.9 E+00	8.5 E-01	NF	1.8 E-01	9.0 E-03	NF	3.1 E-02	4.5 E+01	NF
Ni	1.5 E+02	3.2 E+02	2.1 E+01	9.5 E+00	NF	1.4 E-01	1.3 E-02	5.6 E-01	1.2 E+02	7.5 E+00
Pb	8.2 E+00	5.2 E+01	6.4 E+00	7.2 E+00	1.4 E+00	6.4 E-02	1.4 E-02	3.8 E-02	7.2 E+01	1.0 E+00
Sb	NF	NF	3.9 E+00	NF	NF	1.2 E-02	NF	NF	NF	NF
Se	2.0 E+01	2.4 E+01	2.6 E+00	1.7 E+00	1.8 E+00	7.3 E-01	5.0 E-02	1.6 E-02	NQ	7.2 E+00
Sr	1.9 E+02	3.7 E+02	4.1 E+01	2.1 E+01	8.3 E+00	NF	1.0 E-01	2.1 E+00	6.1 E+02	4.4 E+00
Tl	NF	NF	NF	4.2 E-01	NF	NF	NF	NF	NF	NF
V	1.4 E+01	1.0 E+02	5.7 E+00	5.3 E-01	NF	NF	NF	1.0 E-01	9.0 E+00	NF
Zn	1.4 E+02	2.1 E+00	9.8 E+01	3.0 E+01	1.5 E+01	1.4 E-01	2.8 E-01	1.2 E+00	1.6 E+03	3.1 E+01

NF = Not Found, below detection limits

NQ = present, but Not Quantifiable

TABLE C.8-3. KOSOVO BY-PRODUCTS DENSITY DATA

By-Product	Density (g/L)
Naphtha	845
Medium Oil	972
Light Tar	1059

Aqueous stream trace element mass flow rates are found using Equation 3:

$$M_i = C_i \left(\frac{1\ \text{g/m}^3}{\text{mg/L}}\right)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right) V_T \qquad (13)$$

where: M_i = mass flow rate of element i in kg/gasifier-hr

C_i = concentration of element i in mg/L

V_T = volumetric total stream flow in m^3/hr.

The following is an example of this calculation for As in the Phenosolvan inlet water:

$$\text{Phenosolvan Inlet Water As Mass Flow} = \left(\frac{1.0\text{E-01 mg}}{\text{L}}\right)\left(\frac{1\text{g/m}^3}{\text{mg/L}}\right)\left(\frac{1\ \text{kg}}{1000\ \text{g}}\right)\left(\frac{13\ \text{m}^3}{\text{hr}}\right)$$

$$= 1.3\text{E-03 kg/gasifier-hr}$$

For gaseous streams, elemental mass flow rates were determined by Equation 14:

$$M_i = C_i \left(\frac{1\ \text{kg}}{10^9\ \mu\text{g}}\right) V_T \qquad (14)$$

where: M_i = mass flow rate of element i in kg/gasifier-hr

C_i = concentration of element i in $\mu g/m^3$

V_T = volumetric total stream flow in m^3/hr

For example, the As mass flow in the L.P. coal lock vent gas is:

$$\text{LP Coal Lock As Mass Flow} = (1.7\text{E-03}) \left(\frac{1\ \text{kg}}{10^9\ \mu\text{g}}\right) (21) = 3.6\text{E-05 kg/gasifier-hr}$$

The accountabilities reported in Table C.8-1 were calculated using Equation 7. The dried coal was used as the inlet stream.

APPENDIX D

TABLE D-1. PROPOSED DMEG VALUES

MEG Category	Constituent	Proposed DMEG Value
50	Antimony	7.25E2(W,H)[1,2] 6.0E2(W,E)
49	Arsenic	2.0E0(W,H) 2.9E1(W,E)
15	Benzene	1.5E3(W,H) 4.6E3(W,E)
32	Beryllium	8.7E0(W,H) 8.25E2(W,E)
37	Boron	7.5E2(W,E)
	BOD	2.0E5(W,E)
82	Cadmium	5.0E0(W,E)
53	Carbon disulfide	3.0E3(A,H)
53	Carbonyl sulfide	3.8E3(A,H)
68	Chromium	8.0E-1(W,H) 5.0E1(W,E)
78	Copper	5.0E3(W,H) 3.95E0(W,E)
47	Cyanide (HCN)	5.0E3(A,H) 1.0E3(W,H) 7.0E0(W,E)
1	Ethylene	2.4E1(A,E)
8	Formic acid	1.75E4(W,E)
53	Hydrogen sulfide	2.5E4(A,E)
46	Lead	2.5E2(W,H) 2.22E4(W,E)

(Continued)

TABLE D-1. (Continued)

MEG Category	Constituent	Proposed DMEG Value
83	Mercury	1.0E0(W,H) 3.2E-1(W,E)
76	Nickel	2.5E2(W,H) 1.1E3(W,E)
	Oil and Grease	5.0E2(W,E)
18	Phenol	1.7E4(W,H) 3.0E3(W,E)
54	Selenium	2.2E1(W,E)
79	Silver	5.0E1(W,H) 4.5E-2(W,E)
28	Sodium	1.0E5(W,H)
53	Sulfide	2.5E2(W,H) 1.0E1(W,E)
53	Sulfate	1.3E6(W,H) 4.26E4(W,E)
53	Thiocyanate	8.70E3(W,E)
45	Tin	3.0E4(W,H)
	TDS	1.3E6(W,H) 2.5E6(W,E)
15	Toluene	8.7E4(W,H) 5.0E2(W,E)
81	Zinc	8.44E4(W,E)

[1] aEb = a x 10^b

[2] Letters in parentheses indicate applicability of DMEG value; W,H = Water, health; W,E = Water, ecology; A,H = Air, health; A,E = Air, ecology.

APPENDIX E

GLOSSARY OF TERMS AND ACRONYMS

AA - atomic absorption spectrophotometry
AA,ETA/DA - atomic absorption spectrophotometry, electro thermal atomization (graphite furnace)/deuterium arc
AMES' - salmonella mutagenesis assay
ASTM - American Society for Testing and Materials
B(a)p - benzo(a)pyrene
BOD - biological oxygen demand
CHO - chinese hamster ovary clonal toxicity assay
COD - chemical oxygen demand
DIN - Deutsche Einheitsuerfahren zeir Wasser Untersuchung (German Institute for Standardization)
DMEG - discharge multimedia environmental goal; target value for a component in a discharge stream (SAM/1A model)
DMSO - dimethylsulfoxide
DS - discharge severity = discharge concentration ÷ DMEG (SAM/1A Model)
E - exponent; aEb = a x 10^b
EC$_{50}$ - effective concentration of a substance for 50% positive effects
EP - extraction procedure specified by the Resource Conservation and Recovery Act
GC - gas chromatography
GC/FID - gas chromatography/flame ionization detector
GC/MS - gas chromatography/mass spectrometry
GOST - Soviet State Committee on Standards
HHV - higher heating value
IERL - Industrial Environmental Research Laboratory (U.S. Environmental Protection Agency)
LHV - lower heating value

Mg - megagram = 1 metric ton
MJ - megajoule = ~1000 Btu
MPa - megapascal = ~10 atm
NBS - National Bureau of Standards
Nm^3 - normal cubic meter (25°C & 1 atm)
PNA - polynuclear aromatic hydrocarbon
ppmv - parts per million volume, 1% by volume = 10,000 ppmv
RAM - rabbit alveolar macrophage assay
RCRA - Resource Conservation and Recovery Act
SAM/1A - Source Analysis Model/1A (U.S.-EPA/IERL)
SSMS - spark source mass spectormetry
TA-X - a specific strain of Salmonella typhimurium where x = strain number (AMES assay)
TDS - total discharge severity = ΣDS (SAM/1A model)
TOC - total organic carbon
TWDS - total weighed discharge severity = ΣWDS (SAM/1A model)
WDS - weighed discharge severity = discharge severity x stream mass flow rate (SAM/1A model)
XAD-2 - porous polymer resin for sorption of organic vapors
252 Group - 252 molecular weight polynuclear aromatic hydrocarbons